AFWAL-TR-86-3050

STOL HANDLING QUALITIES CRITERIA FOR PRECISION LANDINGS

Roger H. Hoh
David G. Mitchell

Systems Technology, Inc.
13766 S. Hawthorne Blvd.
Hawthorne, CA 90250

November 1986

Final Report for Period September 1983 - January 1986

Approved for public release; distribution unlimited

FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6553

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specification, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture use, or sell any patent invention that may in any way be related thereto.

This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

Steven R. Sturmer, 1Lt, USAF
Project Engineer
Control Dynamics Branch

Vernon O. Hoehne, Chief
Controls Dynamics Branch
Flight Control Division

FOR THE COMMANDER

Frank A. Scarpino, Chief
Flight Control Division
Flight Dynamics Laboratories

If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization please notify AFWAL/FIGC, W-PAFB, OH 45433-6553 to help us maintain a current mailing list.

Copies of this report should not be returned unless return is required by security considerations, contractural obligations, or notice on a specific document.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for Public Release; Distribution Unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) STI TR-1208-1	5. MONITORING ORGANIZATION REPORT NUMBER(S) AFWAL-TR-86-3050
6a. NAME OF PERFORMING ORGANIZATION Systems Technology, Inc 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Air Force Wright Aeronautical Laboratories Flight Dynamics Laboratory AFWAL/FIGC
6c. ADDRESS (City, State and ZIP Code) 13766 South Hawthorne Blvd Hawthorne CA 90250	7b. ADDRESS (City, State and ZIP Code) Air Force Systems Command Wright-Patterson AFB OH 45433-6553
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable) AFWAL/FIGC	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F33615-83-C-3606
8c. ADDRESS (City, State and ZIP Code)	10. SOURCE OF FUNDING NOS. PROGRAM ELEMENT NO. 62201F; PROJECT NO. 2403; TASK NO. 05; WORK UNIT NO. 55
11. TITLE (Include Security Classification) STOL Handling Qualities Criteria for Precision Landings (U)	
12. PERSONAL AUTHOR(S) Roger H. Hoh, David G. Mitchell	
13a. TYPE OF REPORT Final 13b. TIME COVERED FROM Sep 83 TO Jan 86	14. DATE OF REPORT (Yr., Mo., Day) 1986 November 15. PAGE COUNT 183
16. SUPPLEMENTARY NOTATION cont fr p iii	

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	
01	03		Handling Qualities Criteria; STOL; Precision Landing; Stability Augmentation; Bomb Damaged Runways

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Handling qualities criteria for STOL approaches and landings are developed. The proposed criteria have two elements: (1) the proper Response-type for the task and (2) the minimum attitude and flight path bandwidths. Supporting data is reasonably complete for powered lift STOL aircraft, but less so for fighter STOL's. Fighter STOL's ~~utilize~~ use precision touchdown accuracy and thrust reversing to achieve short field performance. A brief piloted moving base simulation was run on the USAF LAMARS to provide some data. Additional data was correlated from a variable stability inflight simulation of precision landings.

A computer program was written to calculate all potential longitudinal and lateral handling qualities parameters for STOL approaches and landings. Finally, an extensive test plan is intended to provide guidance for future STOL testing. Keywords: LAMARS (Large Amplitude Multimode Research Simulator); stability augmentation.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☒ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL Steve Sturmer	22b. TELEPHONE NUMBER (Include Area Code) (513) 255-8499 22c. OFFICE SYMBOL AFWAL/FIGCB

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

FOREWORD

This report documents an effort to expand on flying qualities design criteria for precision (STOL) landings. The primary emphasis ~~of this work~~ is on non-powered lift, fighter-type aircraft using frontside control technique for longitudinal flight path control. The major thrust of this effort is, therefore, to be able to increase sortie generation due to bomb—damaged runways. The Air Force project engineer was, initially, Thomas J. Cord. This responsibility was later transfered to 2Lt Steve Sturmer. The principal investigator was Roger H. Hoh of Systems Technology, Inc., Hawthorne, California. (to pi)

A special acknowledgement goes to the engineers and operators of the AFWAL Large Amplitude Multi-mode Aerospace Research Simulator (LAMARS) facility; specifically, James M. Zeh, 1Lt Michael Rosenbleeth, and 2Lt Daniel Young. Their knowledge and dedication were invaluable to the conduct of the in-house simulation effort that supported the contract. A special thanks also goes to the test pilots: Lt Col Daniel Biezad, Maj Robert Chedister, Maj Robert Baltzer, Capt Bart Henwood, and Capt John Lansford. Their professionalism was instrumental in providing substantiating data for this work.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF FIGURES (CONCLUDED)

LIST OF TABLES

SECTION I

INTRODUCTION

1. Scope

The purpose of this research effort has been to provide data to expand the proposed MIL Standard and Handbook (Reference 1) to include handling qualities criteria for short takeoff and landing (STOL) aircraft. Since STOL aircraft are unique in the approach and landing flight phases, the criteria development has been concentrated in that area. STOL aircraft are generally characterized in terms of their effective thrust vector orientation, that is, powered lift vs. non-powered lift. The handling qualities of powered lift STOLs were studied extensively in the 1970s, and are reviewed in Reference 3. More recently, a requirement to land fighter aircraft on portions of bomb damaged runways by adding thrust reversing and limited vectoring has been identified. The current goal is to be able to accomplish landings in 1500 ft by 50 ft segments of such runways in visibilities of 700 ft and in 35 kt crosswinds. STOL performance will be achieved via extremely precise control of the touchdown point, and thrust reversing. Since there are no handling qualities criteria for this type of STOL aircraft, the majority of this research has been aimed at the development of such criteria. However, the pertinent criteria and supporting data for powered lift STOLs (from Reference 3) have been included for completeness.

The formulation of handling qualities criteria for non-powered lift STOLs requires supporting data that was not available at the initiation of this research. While it was originally intended to conduct a moving-base simulation to develop at least some substantiating data, such an effort proved to be beyond the scope of the available resources in this program. However, the Air Force was able to provide assistance by conducting a moving-base piloted simulation (albeit somewhat limited in scope). An extensive test plan was developed that consisted of configurations that would fill the gaps in the data base for both longitudinal and lateral handling qualities for non-powered-lift STOLs (see Section V and Appendix B). Several of these configurations were tested on the USAF Large Amplitude Multimode Research Simulator (LAMARS) by AFWAL/FIGC personnel (see Appendix A). In addition, the data from the Reference 2 flared landing study conducted by Calspan on the USAF/AFWAL total in-flight simulator (TIFS), was utilized. That study was oriented toward flared landings of large aircraft, but is useful in terms of identifying the fundamental requirements for precision landings.

The proposed criteria for pitch attitude control are presented in Section II and the criteria for flight path control in Section III. Section III is divided into frontside flight path control (Section III-A), and backside flight path control (Section III-B). Sections II and III are presented in essentially the same format as the current version of the proposed MIL Standard and Handbook to facilitate incorporation of the criteria into these documents if so desired. The supporting data for frontside flight path control is the main topic of the present research and is contained in Section IV. The configurations developed to fill the gaps in the data base are summarized in Appendix B.

2. Background

A recent report (Reference 3) contains a summary of STOL handling qualities data, so the details of these data will not be repeated here. In Reference 3, STOL aircraft were classified into four major categories. These were:

1. Powered-lift STOLs which require the backside closed-loop piloted control technique, i.e., pitch attitude controls airspeed and thrust controls flight path. Examples of such aircraft are the NASA Augmentor Wing and QSRA, and the Douglas YC-15.

2. Powered-lift STOLs that are augmented so the pilot can utilize the frontside control technique, i.e., pitch attitude controls flight path and thrust may or may not be required to effect

changes in the trim airspeed. An example is the Boeing YC-14.

3. Non-powered-lift low-wing-loading STOLs. The De Havilland Twin Otter is such an aircraft.

4. High-wing-loading STOLs with minimal powered lift. While there are no existing aircraft of this type, the task of landing CTOL aircraft aboard aircraft carriers is similar. The fighter STOL mentioned above falls into this class. Such an aircraft will rely on extremely precise flight path control and large amounts of thrust reversing after touchdown. The constraints for their mission will almost certainly demand the frontside piloting technique.

The differences between powered-lift and non-powered-lift STOLs, flown with the frontside technique, may be minimal in terms of handling qualities requirements. However, the lower flight speeds afforded by utilizing powered lift can mean lower approach speeds and sink rates, and less speed to dissipate once on the runway. Typical approach speeds for powered-lift STOLs are 60-80 kt; for non-powered-lift, high-wing-loading aircraft, approach speeds could be as high as 140 kt. Clearly, the landing task carries much greater demand on precision control for the CTOL-like STOL as runway length is decreased.

Reference 3 identified several major shortcomings in the available STOL data base. The critical gaps are outlined below.

- Most of the STOL aircraft flown or simulated have been medium-to-large transport-type aircraft (i.e., Class II and III in MIL-F-8785C, Reference 32). This applies to both non-powered-lift STOLs (the Twin Otter) as well as powered-lift aircraft (e.g., the YC-14, YC-15, Augmentor Wing). Little quantitative data could be found for Class IV STOLs, such as the AV-8A Harrier (which is normally operated in a VTOL environment).

- The bulk of the data were generated during the early-to mid-1970's in response to Federal Aviation Administration interests in Airworthiness Certification for STOLs. Thus, the tasks and operating environments were tailored toward civil, rather than military operations. These data were obtained exclusively on moving-base simulators.

- The only useful flight test data available were for the NASA Augmentor Wing aircraft. Again, this is a large, powered-lift STOL. Since the publication of Reference 3, the flight test reports for the Advanced Medium STOL Transport (AMST) aircraft, the YC-14 and YC-15 (References 25 and 26, respectively), have been reviewed. However, since these were evaluation reports and were not intended for the generation of quantitative handling qualities data, their usefulness is limited to whatever insights that can be obtained from pilot commentary.

- Very little of the existing data could be used to define Level 2 and Level 3 boundaries for flight path control. The civil airworthiness studies were concentrated in the Level 2 region (Cooper-Harper pilot ratings of around 4 to 5).

- A number of STOL criteria for both flight path control and attitude control were available, but there was insufficient data to set definite Flying Quality Levels on these criteria.

- Very little work has been conducted for lateral-directional requirements. In Reference 3, it was emphasized that the CTOL requirements should apply equally for STOLs. However, it is likely that the extreme precision required for non-powered-lift STOLs will require increased bandwidths in the lateral-directional axes.

From the above, the most critical areas for research can be identified. The heaviest interest is for non-powered-lift, fighter-type STOLs since there are essentially no data for this type of aircraft. Data is needed for all STOL types to refine proposed criteria and verify the applicability of existing criteria, especially for Level 2 and 3 operations. Effects of adverse visibility and weather, and tradeoffs between flared and unflared landings, need to be investigated. Lateral/directional handling qualities requirements must be developed.

SECTION II

PITCH ATTITUDE CONTROL

1. Requirement

The bandwidth of the open-loop pitch attitude response to the pitch controller shall have the following characteristics ____________________.

Recommended limits for the pitch attitude bandwidth are given as a function of the parameters ω_{BW_θ} and τ_p in Figure 1. These parameters are defined in Figure 2a. In addition, the subsidence ratio X_2/X_1, defined in Figure 2b, should not exceed 0.31. An attitude command/attitude hold (ACAH) response-type is recommended for STOL landings, although rate command/attitude hold (RCAH) is acceptable (but not ideal) as long as the requirements of Section III-A are met.

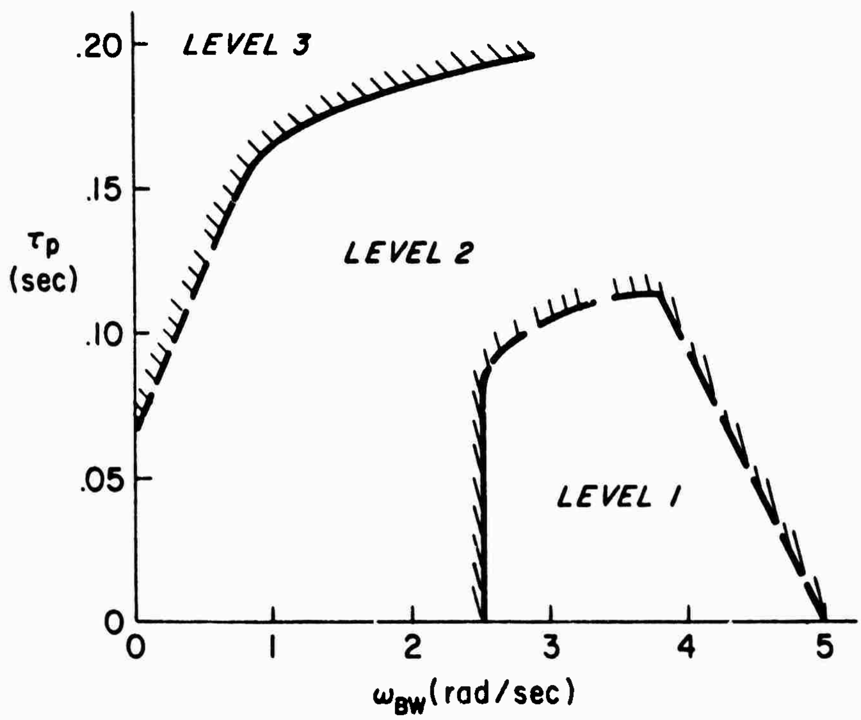
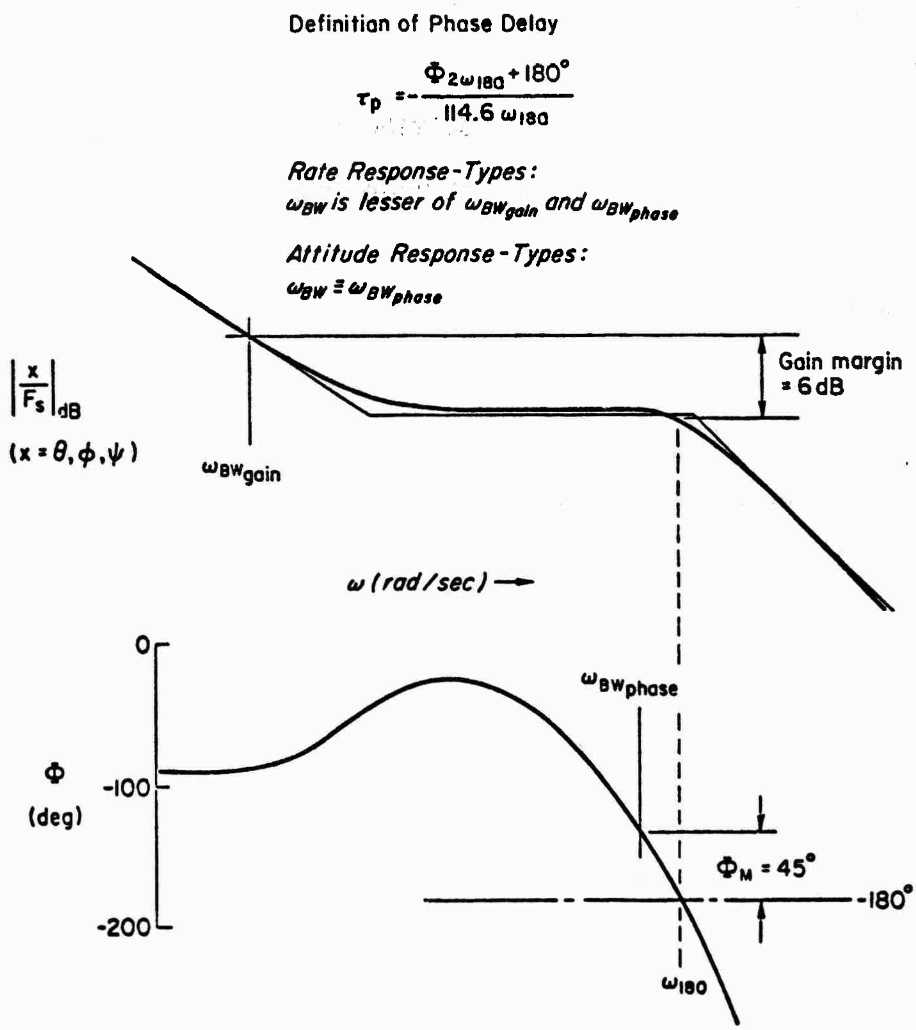
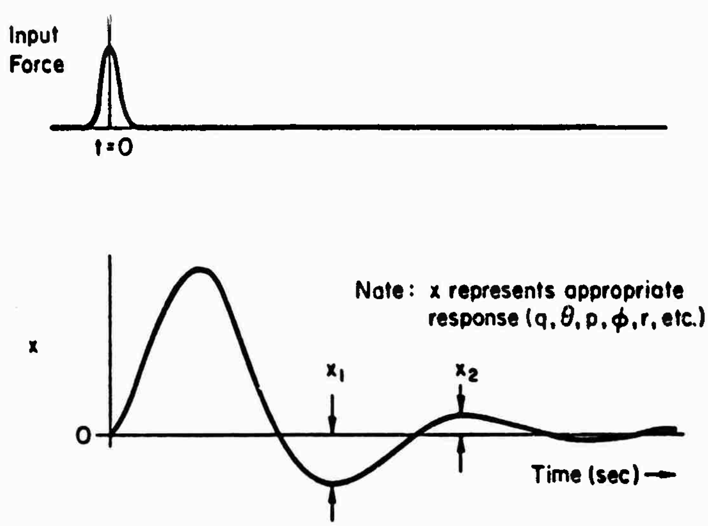


Figure 1. Bandwidth Requirements on Pitch Attitude (From Reference 1)



a) Definitions of Bandwidth and Phase Delay



b) Definition of Subsidence Ratio, x_2/x_1

Figure 2. Definitions of Bandwidth Criterion Parameters

2. Rationale

The bandwidth criterion (defined in Figure 2) is recommended for aircraft where STOL landing is a mission requirement. This is based on the fact that the use of Lower Order Equivalent Systems is not possible with the recommended attitude command/attitude hold response-type, and has questionable validity for rate command/attitude hold (this is discussed in more detail in Section IV-E). The recommended criterion boundaries in Figure 1 are identical to the proposed Category C boundaries for conventional aircraft (Reference 1). This is based on the results of the Appendix A simulation as well as the flight tests in Reference 2 (the test aircraft was not a STOL, but the task involved precision landings). This is discussed under supporting data for frontside flight path control (Section IV).

A subsidence ratio requirement has been added to the ω_{BW_θ} and τ_p parameters from Reference 1 to account for the fact that a damping ratio of less than 0.35 can be obtained while still meeting the Level 1 boundaries in Figure 1. While it is extremely unlikely that an attitude or rate augmentation scheme would ever be designed with $\zeta < 0.35$, it is possible that the failure of a pitch damper could cause a loss in damping which would be caught by the subsidence ratio limit.

Reference 3 suggested a possible relaxation in attitude bandwidth if the aircraft is flown backside in the flare (i.e., flare with power). However, while such flaring with power may be perfectly acceptable (Section III-B), it is felt that the integrity of the attitude response should be maintained for the de-rotation task after touchdown, as well as rotation to the takeoff attitude.

3. Supporting Data (Guidance)

The supporting data for this section is given in the proposed MIL Standard and Handbook, Reference 1 (page 178), since it is unchanged from the CTOL requirement. Further substantiation is given in Section IV (Figure 23) based on the results of the Appendix A simulation and the Reference 2 flight tests.

The Reference 2 flight tests do not, however, support the limits on τ_p in Figure 1, and in fact much higher time delays (0.2 to 0.3 sec) result in Level 1 ratings. It is not clear whether these results are due to the large-airplane orientation of the Reference 2 test, or are an indication that the strong sensitivity of pilot rating to increasing time delay (approximately 1 rating per 0.05 sec of time delay, for which τ_p is an approximation) predicted in References 4 and 5 are not correct. It is proposed that the current, more stringent limits on τ_p be retained until landing tests with more agile aircraft are conducted. It does appear, however, that a relaxation on τ_p for large aircraft is warranted based on the Reference 2 results.

SECTION III

FLIGHT PATH CONTROL

The piloting technique utilized for flight path control depends on whether the aircraft is on the backside or frontside of the power-required curve, and on the inclination of the thrust vector in the power-approach flight condition. Most "conventional" takeoff and landing (CTOL) aircraft operate on the frontside ($d\gamma/dV$ is negative) and the majority of the thrust is pointed aft, whereas powered-lift configurations tend to operate on the backside ($d\gamma/dV$ is positive), with a large portion of the thrust oriented normal to the flight path. For CTOLs, flight path is controlled with pitch attitude, and airspeed with thrust. For powered lift STOLs, thrust is used to control flight path, and pitch attitude to control airspeed, except for the flare, which is usually accomplished with attitude. Fighter STOL configurations would tend to operate in a region where $d\gamma/dV = 0$ and have most of the thrust oriented aft. Because of the aft thrust orientation, short-term flight path corrections would be accomplished with attitude, and airspeed control, as well as long-term flight path corrections, accomplished with throttle.

Requirements are necessary for both the frontside and backside control techniques. Such requirements, along with rationale and supporting data, are presented in the following paragraphs.

A. FRONTSIDE FLIGHT PATH CONTROL

1. Requirements

a. The lag between flight path and pitch attitude shall fall within the following limits __________.

b. The angle-of-attack response to a step longitudinal controller input shall exhibit zero slope within the first ______ seconds from initiation of the step controller input, and shall be generally characterized as a step response during that period.

c. If Requirement b is not satisfied, or is questionable, an acceptable alternative shall be to demonstrate that the bandwidth of flight-path-angle to longitudinal controller input, ω_{BW_γ}, is greater than _____.

d. The magnitude of the peak flight-path-angle change following a step change in pitch attitude shall exceed _______.

Compliance with Requirement a is to be demonstrated at the minimum allowable approach speed specified for the aircraft. Compliance with Requirements b, c, and d is to be demonstrated at the minimum expected airspeed at flare initiation, or at touchdown if no-flare landings are specified.

Recommended limits

a. The recommended limits for the effective lag between pitch attitude and flight path (see Figure 3) are as follows:

$$\text{Level 1} \quad 0.38 < \left(1/T_{\theta_2}\right)_{eff} < \frac{0.77\,\omega_{BW_\theta}}{K\zeta + \sqrt{K^2\zeta^2 + 1}}$$

$$\text{Level 2} \quad 0.24 < \left(1/T_{\theta_2}\right)_{eff} < \frac{1.33\,\omega_{BW_\theta}}{K\zeta + \sqrt{K^2\zeta^2 + 1}}$$

Where ζ is obtained from the subsidence ratio (Figure 2b) according to Figure 4, or a conservative default value of 1.3 may be used.*

$K = 1$ for ACAH response-type

$$K = \frac{\omega_{BW_\theta} - 1/T_q}{\omega_{BW_\theta} + 1/T_q} \text{ for RCAH response-type}$$

*These approximations assume $\tau_p = 0$.

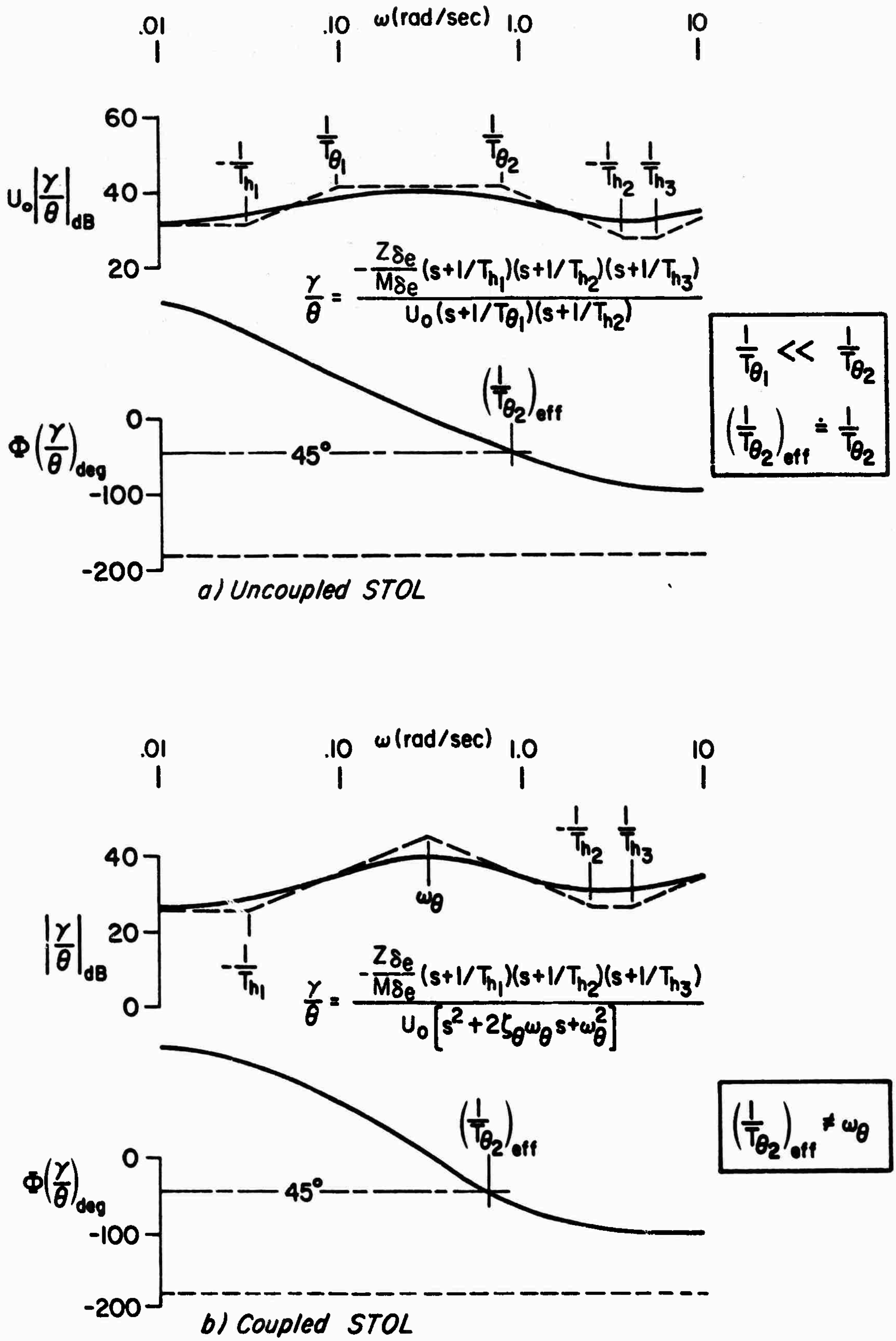
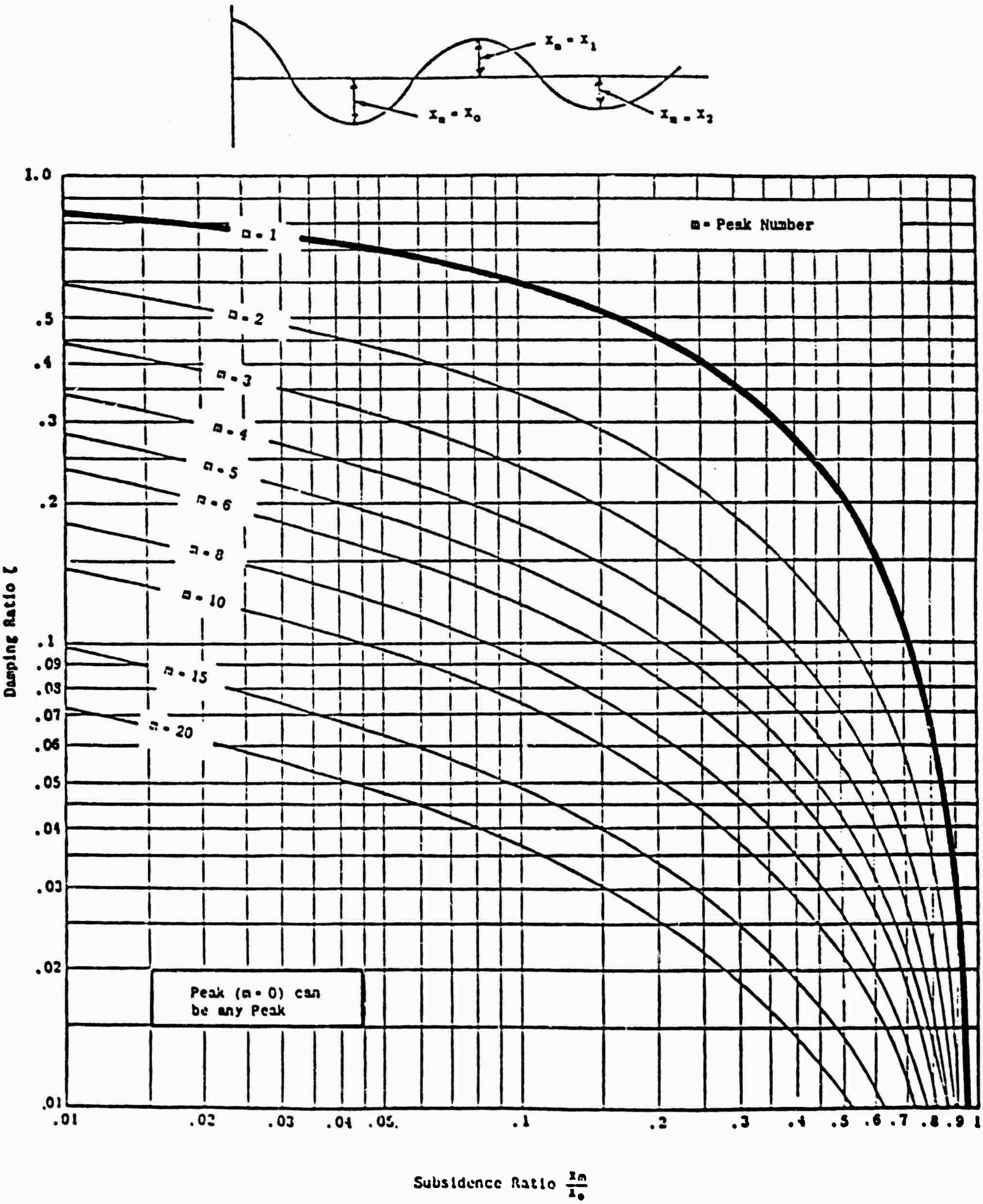


Figure 3. Definition of Effective Path/Attitude Lag, $(1/T_{\theta_2})_{eff}$



$$\frac{s}{\frac{s^2}{\omega_n^2}+\frac{2\zeta}{\omega_n}s+1}, \quad \frac{1}{\frac{s^2}{\omega_n^2}+\frac{2\zeta}{\omega_n}s+1}, \quad \frac{1}{s\left[\frac{s^2}{\omega_n^2}+\frac{2\zeta}{\omega_n}s+1\right]}$$

Figure 4. Damping Ratio of Oscillatory Transients as a Function of Subsidence Ratio for Second-Order Systems (from Reference 35)

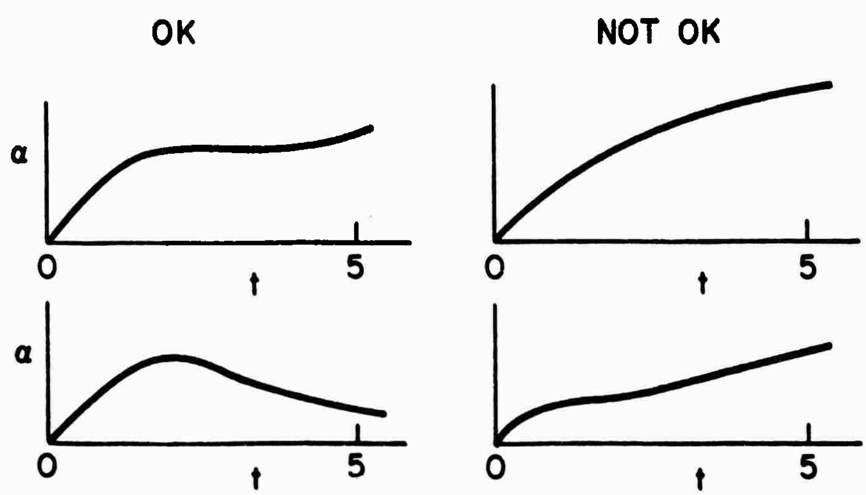
Where $1/T_q$ is the numerator zero of the q/δ_{es} transfer function (see Section IV).

If an equivalent short period frequency has been calculated, the following relationships apply:

$$\text{Level 1} \quad 0.38 < \left(1/T_{\theta_2}\right)_{eff} < 0.77\ \omega_{sp}$$

$$\text{Level 2} \quad 0.24 < \left(1/T_{\theta_2}\right)_{eff} < 1.33\ \omega_{sp}$$

b. The short-term angle-of-attack response should have zero slope within the first five seconds following a step longitudinal controller input. Examples of acceptable and unacceptable angle-of-attack responses are shown in the following sketch.



c. If Requirement b is not satisfied, or is questionable, the bandwidth of the flight-path-angle response to the longitudinal controller input (where bandwidth is defined in a manner identical to pitch attitude bandwidth, Figure 2a, with γ in place of θ), should be no less than the following:

	LEVEL 1	LEVELS 2 and 3
ω_{BW_γ} (rad/sec)	0.80	0.60

d. The magnitude of the peak flight-path-angle response following a step change in attitude should be no less than the following.

	LEVEL 1	LEVELS 2 AND 3
$\frac{\Delta\gamma_{max}}{\Delta\theta_{ss}}$	0.70	0.50

2. Rationale

The requirement on flight path lag relative to pitch attitude (Requirement a) is directed at flight path control during the landing approach where the bandwidth of the pitch attitude loop is characteristically much higher than that of the path loop. The requirements for a step-like angle-of-attack response, a minimum level of flight path bandwidth, and a minimum $\Delta\gamma_{max}/\Delta\theta_{ss}$ are all based on the requirement for precision touchdown.

3. Supporting Data

a. Flight Path Control for Landing Approach

The limits on $(1/T_{\theta_2})_{eff}$ were taken from Reference 3. The lower limit is based on approach data from flight tests with a CTOL NT-33A. This data is felt to apply to STOLs as well since no unique requirements have been determined for STOL flight path control in the approach flight phase. In fact, the results of Reference 6 indicate that the flight path dynamics during the approach are surprisingly non-critical, and that the requirements for short final and landing establish the flying qualities limits. As noted in Reference 3, the lower limit on $(1/T_{\theta_2})_{eff}$ is equivalent to the lower limit on n/α for CTOL aircraft at 135 kts. Interestingly, the lower limits on n/α in MIL-F-8785C are based on a minimum $1/T_{\theta_2}$ which was converted to n/α.

The upper limit on $(1/T_{\theta_2})_{eff}$ is based on experience which has shown that the path response bandwidth should be well separated from the pitch response bandwidth (see, e.g., References 18 and 36).

Evidence to support this is given in the analysis and flight test results obtained by DFVLR (using an HFB-320 in-flight simulator) and reported in Reference 7. These results indicate that an appropriate criterion parameter would be the phase angle between path and attitude at the short-period frequency, i.e.,

$$\phi(\gamma/\theta)\Big|_{\omega=\omega_{sp}}$$

Noting that $\phi(\gamma/\theta)\Big|_{\omega=\omega_{sp}} = \tan^{-1} \omega_{sp}T_{\theta_2}$, a criterion on $\omega_{sp}T_{\theta_2}$, proposed in Reference 1, can be easily converted to $\phi(\gamma/\theta)\Big|_{\omega=\omega_{sp}}$ with the results shown in Table 1. The upper limits on $1/T_{\theta_2}$ in Requirement a were obtained from the values of $(\omega_{sp}T_{\theta_2})_{min}$ in Table 1, which in turn were taken from the Category C requirements in the proposed MIL Handbook (Reference 1). The upper limits on $1/T_{\theta_2}$ could also be considered as a lower limit on ω_{sp}. This, of course, is a direct consequence of the physical interpretation of $\omega_{sp}T_{\theta_2}$ as a measure of path/attitude consonance. More specifically, when controlling flight path with pitch attitude, the pilot desires that the path response lag the attitude response. Unfortunately, there is not a great deal of data to document this particular aspect of the pilot-centered requirements for path control; that is, very few experiments include configurations where $1/T_{\theta_2}$ is nearly equal to or greater than ω_{sp}. For now we must rely on Reference 7 as well as undocumented pilot commentary from various sources to support the path/attitude consonance requirement; however, our rationale leads us to avoid a situation where $1/T_{\theta_2} > \omega_{sp}$. This conclusion was reached independently by other researchers (i.e., References 7 and 8) but not by those using fixed base simulation. This suggests that the requirement for $1/T_{\theta_2} < \omega_{sp}$ is a result of aircraft motion.

TABLE 1. CONVERSION OF $\omega_{sp}T_{\theta_2}$ TO A PHASE ANGLE CRITERION

CATEGORY	LEVEL	$(\omega_{sp}T_{\theta_2})_{min}$ (Reference 1)	MAXIMUM ALLOWABLE $\phi(\gamma/\theta)\|_{\omega=\omega_{sp}}$ (deg)
A	1 2	1.6 1.0	-58 -45
B	1 2	1.0 0.58	-45 -30
C	1 2	1.3 0.75	-52 -37

The phase angle criterion in Table 1 would be applicable as an alternate to the upper limit on $(1/T_{\theta_2})_{eff}$ for interpreting simulator or flight test results.

The proposed criterion is written in terms of ω_{BW_θ} (instead of ω_{sp}) as a matter of convenience to the user. ω_{BW_θ} is related to ω_{sp} by the following relationships (see Reference 9, page 210):

$$\frac{\omega_{BW_\theta}}{\omega_{sp}} = K\zeta_{sp} + \sqrt{K^2\zeta_{sp}^2 + 1}$$

$$K = 1 \text{ for ACAH response-type}$$

$$K = \frac{\omega_{BW_\theta} - 1/T_q}{\omega_{BW_\theta} + 1/T_q} \text{ for RCAH response-type}$$

Combining these values with the Category C limits on $(\omega_{sp}T_{\theta_2})_{min}$ from Table 1 yields the specified upper limits on $(1/T_{\theta_2})_{eff}$. The relationship between ω_{BW_θ} and ω_{sp} involves the damping ratio which can be obtained from the subsequence ratio (X_2/X_1 in Figure 2b), or a conservative default value of 1.3 may be used. The parameter $1/T_q$ is the numerator of the pitch rate response which is simply the ratio of the attitude (or integral of rate) to rate gain (K_θ/K_q). This is further clarified in Section IV.

Determination of $(1/T_{\theta_2})_{eff}$ requires a frequency sweep and subsequent manipulation of the data using Fast Fourier transforms. An alternative (and much simpler) approach is to utilize the linear relationship between the rise time in γ following a step change in θ, and $(1/T_{\theta_2})_{eff}$ defined in Reference 3 and shown in Figure 5.

b. Flight Path Control for Precision Landings

The proposed requirements for precision landings (b, c, and d) are new, and represent a substantial portion of this research effort. Therefore, an entire section of the report (Section IV) has been allocated to the development of the precision landing criteria.

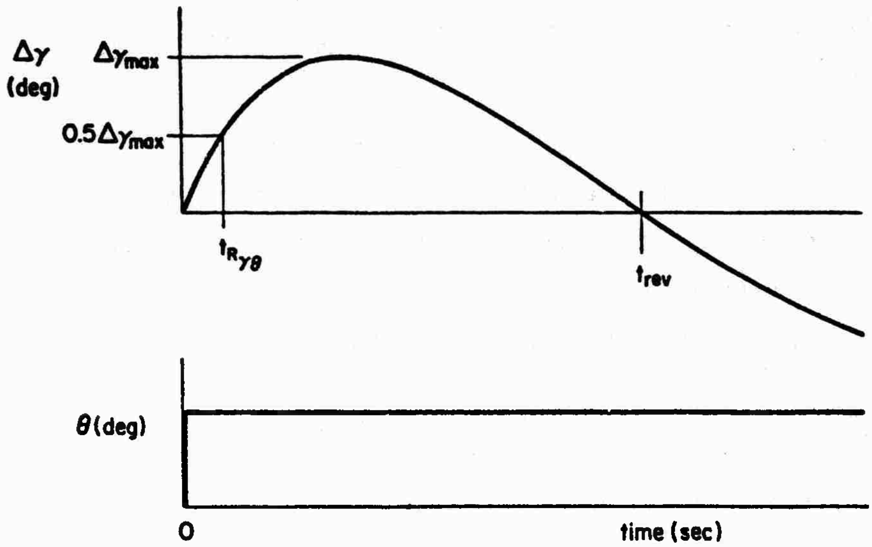
B. BACKSIDE FLIGHT PATH CONTROL

The requirement, rationale, and supporting data presented in this section are taken from Reference 3 with some minor modifications.

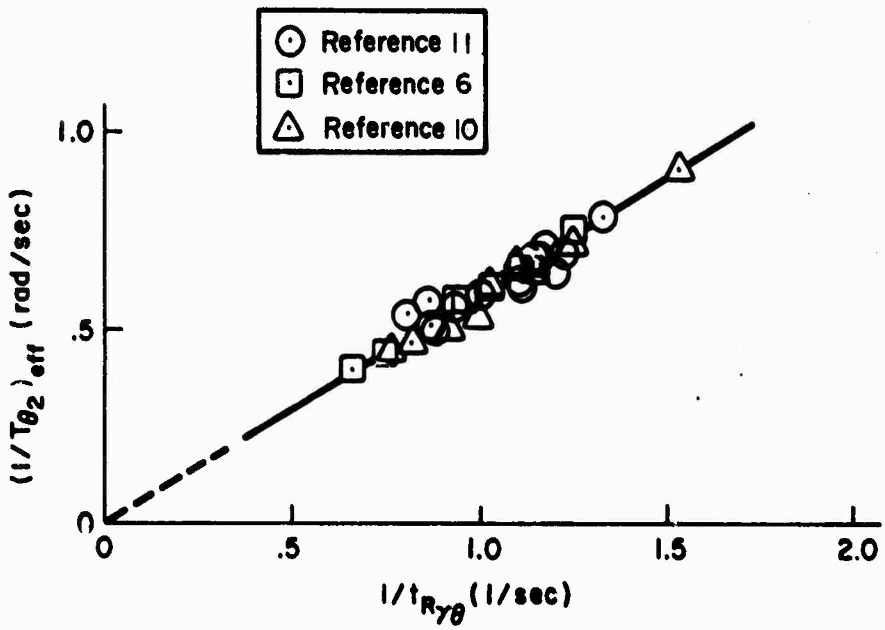
1. Requirement

The short-term flight path response to designated flight path controller inputs shall have the following characteristics: _____________.

Recommended values: Effective rise time, $t_{R_{\gamma T}}$, and overshoot ratio, $\Delta\gamma_{max}/\Delta\gamma_{ss}$, following a step change in designated flight path controller, should be within the Level 1 boundaries of Figure 6. There are insufficient data to define the boundary between Level 2 and Level 3. Aircraft which fall outside the Level 1 boundaries in Figure 6 should be required to have Level 1 vertical axis response to attitude changes, i.e., they should meet the requirements of the previous subsection (III-A).



a) Definition of γ/θ Time Response Parameters



b) Relationship Between $(1/T_{\theta_2})_{eff}$ and Rise Time for Typical Powered-Lift STOLS

Figure 5. Conversion of Effective Path/Attitude Lag to a Time Response Parameter

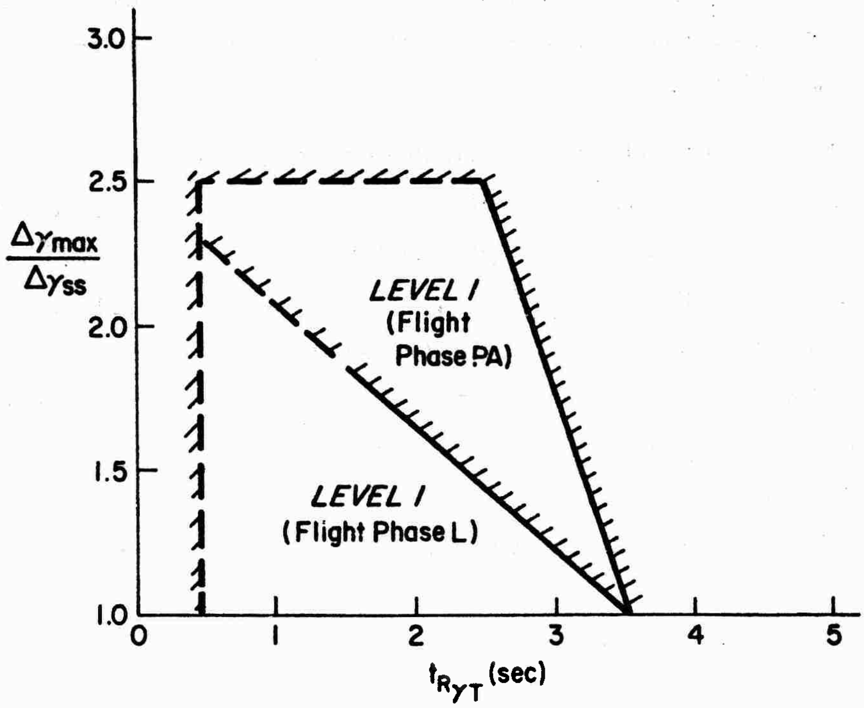


Figure 6. Level 1 Limits for Short-Term Vertical Axis Response to Step Input of Designated Flight Path Controller

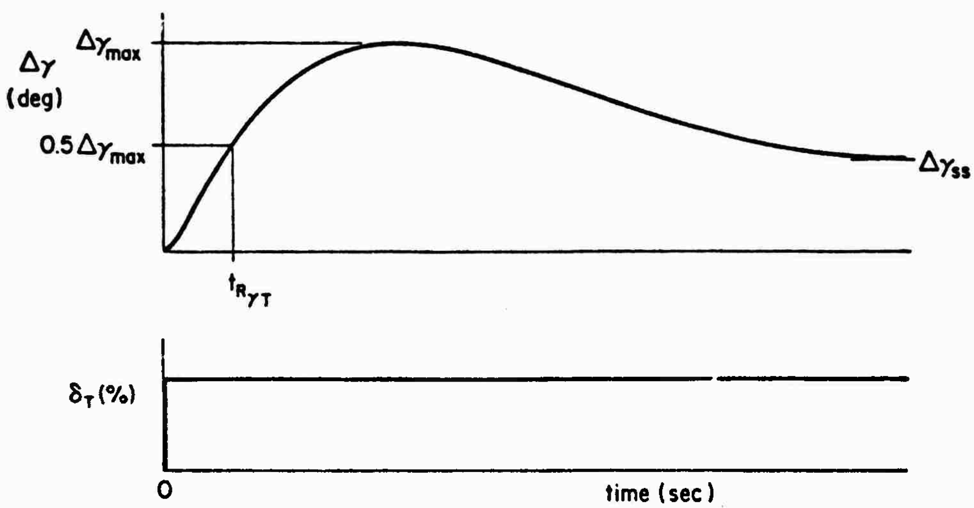
2. Rationale

This paragraph is applicable to aircraft equipped with a designated flight path controller other than pitch attitude. The form of controller is irrelevant; STOL designs have used spoilers, flaps, nozzle vectoring, and throttles to provide flight path control. Throughout these requirements the controller will often be described as "throttle" for convenience, since "designated flight path controller" is unwieldy. The use of "throttle" to represent the flight path controller should not be construed to indicate any preconceptions as far as specific design.

It would be expected that a designated flight path controller will be required for most powered-lift aircraft because: 1) a significant component of the thrust vector is vertical, and/or 2) the aircraft operates well on the backside of the power required curve.

Separate criterion boundaries are specified for Landing and Approach in Figure 6. Aircraft with flight-path-to-throttle characteristics which meet the approach boundaries, but not the landing criterion, are expected to meet the criteria for precision landings with pitch attitude in Section III-A-b.

The most important short-term requirements for the designated flight path controller are rapidity of response and effectiveness in changing the flight path. Rapidity is defined here in terms of rise time, $t_{R_{\gamma T}}$, and overshoot ratio, $\Delta\gamma_{max}/\Delta\gamma_{ss}$, determines how well the commanded flight path change stabilizes in the short term. Figure 7 illustrates how $t_{R_{\gamma T}}$ and $\Delta\gamma_{max}/\Delta\gamma_{ss}$ are defined. Note that $t_{R_{\gamma T}}$ is identical to the parameter $t_{0.5\Delta\gamma_{max}}$ of Reference 10, and that it is related to the bandwidth of h/δ_T (normal pitch SAS on) as defined in Figure 8. Figure 9 shows the relationship between $\omega_{BW_{hT}}$ and $t_{R_{\gamma T}}$ for the data of References 6 and 11. This figure may be used to convert the Figure 6 requirement to $\omega_{BW_{hT}}$ vs. $\Delta\gamma_{max}/\Delta\gamma_{ss}$, if desired.



Note: Pitch attitude controller is free during response

Figure 7. Definition of γ/δ_T Time Response Parameters (Pitch SAS Active)

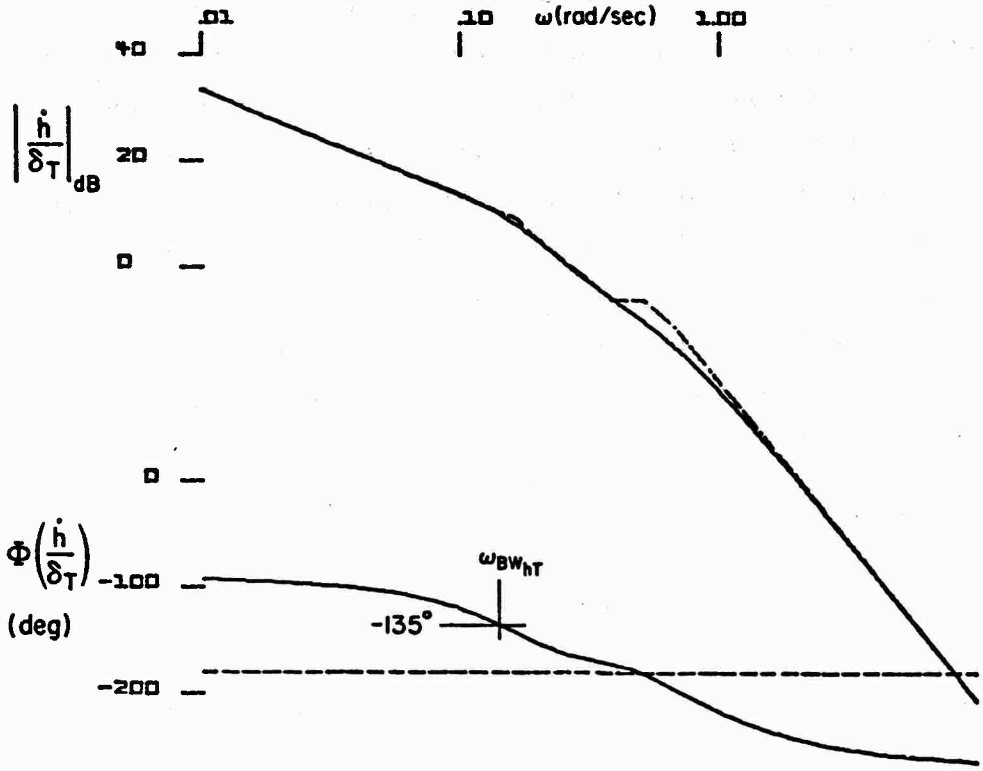


Figure 8. Definition of $\dot{h}/\delta_T$ Frequency Response Parameter (Pitch SAS Active)

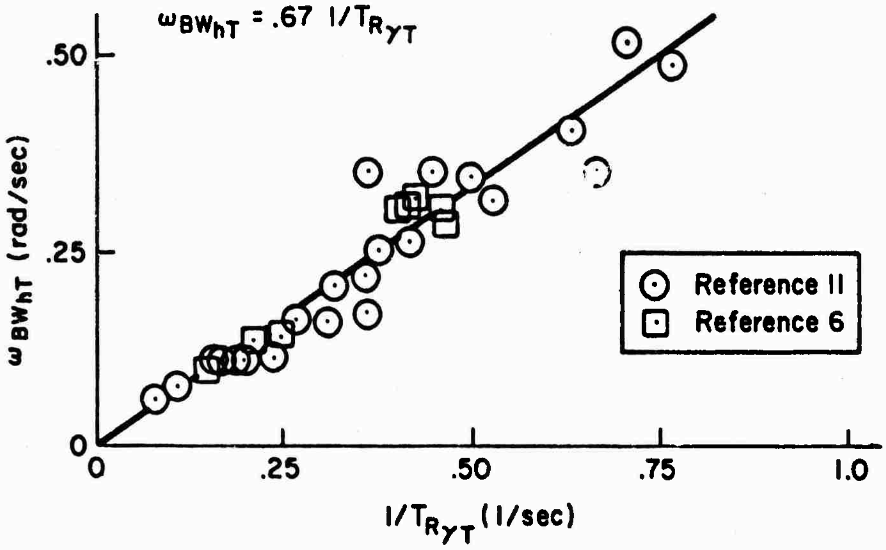


Figure 9. Relationship Between Throttle Bandwidth and Rise Time for Typical Powered-Lift STOLs

The limits of Figure 6 reflect pilot acceptance of less precise flight path control (i.e., more overshoot) during the approach than for flare and landing. For flare, large path overshoots generally lead to high workload and touchdown dispersions. The dashed lines on the Level 1 boundaries reflect uncertainty (primarily due to a lack of data) in setting a lower limit on $t_{R_{\gamma T}}$. It is certain that the excessive abruptness consistent with $t_{R_{\gamma T}} \rightarrow 0$ would be unacceptable to the pilot. However, the lower limit on $t_{R_{\gamma T}}$ in Figure 6 is not based on any existing data and should be the subject of piloted simulation or flight test experimentation.

3. Supporting Data

The requirements proposed for backside flight path control are taken from Reference 3. Supporting data is developed extensively in Reference 3 and is presented herein in a slightly abridged form.

a. Approach Data

An extensive review of configuration characteristics and pilot comments from References 6 and 10 through 13 (discussed extensively in Reference 3) shows that, with only one exception, all the aircraft tested were flown using STOL technique ($h \rightarrow \delta_T$, $u \rightarrow \theta$) on final approach. This was to be expected, since all these aircraft represented powered-lift designs. The single exception was a simulated aircraft with an effective horizontal thrust inclination and adequate path/attitude bandwidth (Reference 11) -- i.e., a non-powered-lift CTOL-type airplane. It should be noted that many of the Reference 6 configurations were on the frontside of the power required curve, but that the pilot still utilized the STOL technique for flight path control. This was primarily because of the large thrust inclination angle that renders throttle ineffective as a speed controller. In fact, a review of the pilot commentary reveals that speed/path coupling was actually adverse in many cases, i.e., speed decreased with a power addition. Path/speed coupling is further discussed in Reference 11.

One measure of the extent of powered lift is the effective thrust angle, θ_T, given by $\theta_T = \tan^{-1}(-\frac{Z_{\delta_T}}{X_{\delta_T}})$, X_{δ_T}, Z_{δ_T} in stability axes. Thus θ_T = 90 deg is a purely vertical component. The parameters $t_{R_{\gamma T}}$ and $\Delta\gamma_{max}/\Delta\gamma_{ss}$ can be related to θ_T. Figure 10 shows the generic effect of θ_T on flight path response. As this figure suggests, sluggish rise time ($t_{R_{\gamma T}}$ large) is often associated with relatively horizontal thrust inclination, while overshoot ($\Delta\gamma_{max}/\Delta\gamma_{ss} > 1$) occurs as a result of relatively vertical thrust inclination.

Figure 11 is a summary of the ratings from References 6 and 10 through 13. The test conditions, vehicles flown, and facilities are described in detail in Reference 3 and are summarized in the following table.

REF	TEST FACILITY	AIRCRAFT	VARIABLES
13	FSAA (Simulator)	BR941S	U_o, γ_o, σ_{u_g}, Transparency
12	FSAA	Augmentor Wing	U_o, γ_o, Winds, T_{ENGINE}
6	S-16 (Simulator)	Generic Powered-Lift	U_o, h_o, γ_o, σ_{u_g}, Winds
6	Princton VSA (Flight)	Navion	
11	FSAA	Generic Powered-Lift	σ_{u_g}, Winds, T_{ENGINE}
10	Augmentor Wing	AWJSRA	X_w, Z_w, θ_T

The flight test data on Figure 11 have poorer pilot ratings than the simulations. The reasons for this are not fully known, although it is possible that the overall flight test environment (which almost always included some winds and turbulence) was more severe than the simulated environments. This degradation in pilot ratings in flight test was found in Reference 6, where similar configurations were evaluated in both environments (compare simulator and Navion data on Figure 11).

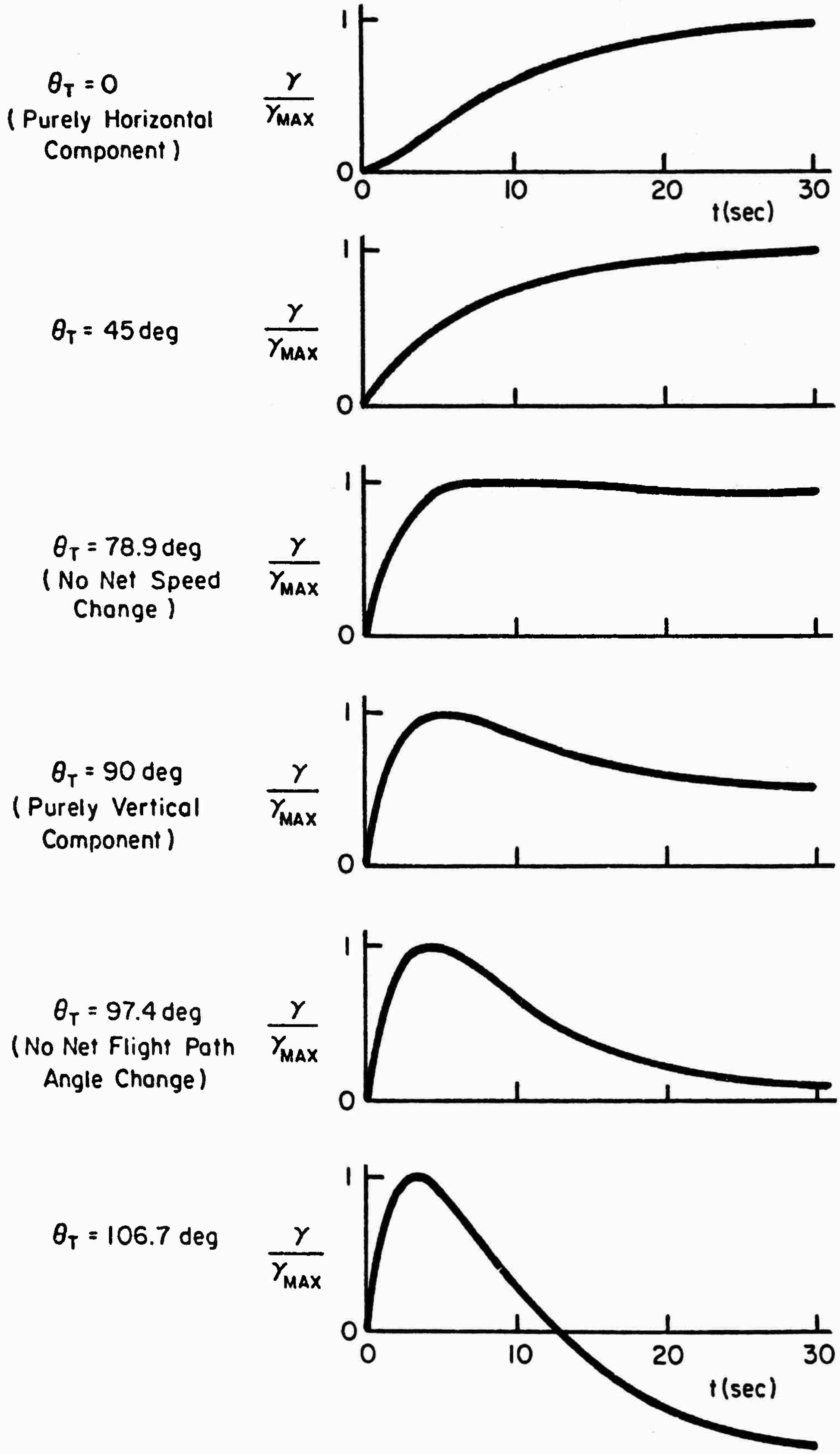


Figure 10. Shape of γ Response to Step δ_T for Varying θ_T

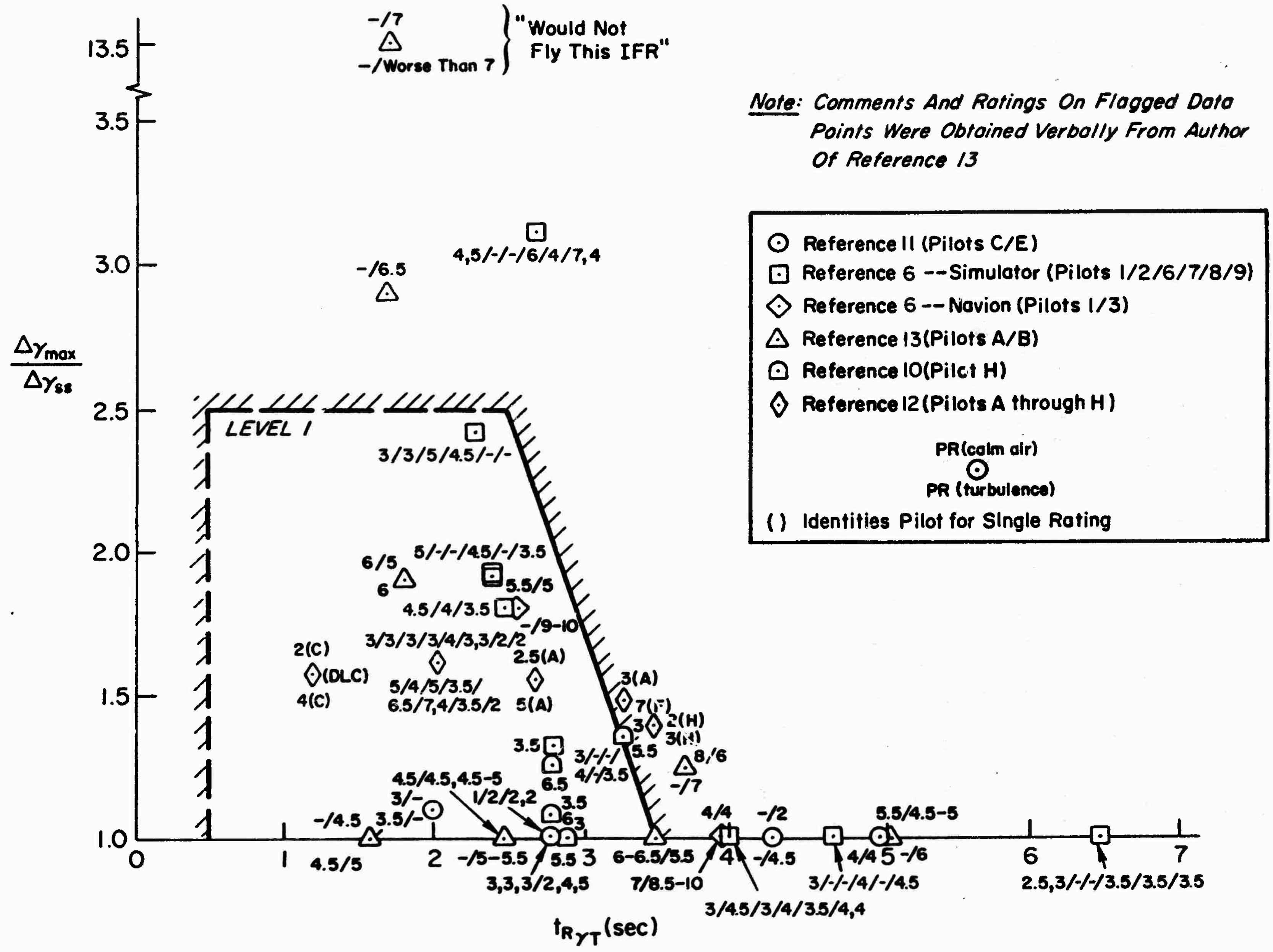


Figure 11. Pilot Ratings for Backside Control of STOL Aircraft in Landing Approach

It is important to remember that the proposed MIL Handbook (Reference 1) allows a degradation in pilot ratings due to turbulence; for example, the Level 1 limit drops from 3-1/2 to 5-1/2. Therefore a rating of 5 in moderate turbulence is equivalent to a 3 in calm air. This two-point shift is supported by the data of Figure 11 (where pilot ratings below the symbol are with turbulence).

There is considerable scatter in the ratings shown in Figure 11. For example, in one case Level 1 pilot ratings were given to a configuration with an extremely sluggish response ($t_{R_{\gamma T}}$ = 6.5 sec). This is explained by the good short-term path/attitude characteristics of this configuration [$(1/T_{\theta_2})_{eff}$ = 0.75 rad/sec; Configuration BSL2 from Reference 6]. The pilot comments for BSL2 verify that the pilot used throttle for basic path control, but relied on pitch attitude for quickening the path response. In fact, the primary reason the pilots stated that they used the backside technique on this configuration was that the thrust inclination was nearly vertical, making it impossible to control airspeed with power.

The boundaries drawn are based on a combination of the data shown, and on what previous researchers have recommended. For example, Reference 10, using most of the same data, suggested $t_{R_{\gamma T}}$ less than 3 sec. The AMST specification (Reference 16) defined the rise time for reaching 90 percent of steady-state, and set the limit at 5 sec for flight at the minimum operational speed. For a typical h/δ_T response this would be equivalent to $t_{R_{\gamma T}}$ of approximately 2.8 sec.

Data from Reference 15 are given in Figure 12. These data are from an FSAA simulation of the Augmentor Wing with variations in X_u, X_w, and θ_T. The data were not included on Figure 11 because the task in this experiment only included ILS tracking -- a relatively undemanding task. This is reflected in Figure 12 where the Reference 15 data are compared with the proposed boundaries. The fact that Level 1 pilot ratings were given to configurations with very sluggish response characteristics ($t_{R_{\gamma T}}$ = 5) emphasizes the fact that the visual portion of the landing task on short final and in the flare is much more demanding than the ILS approach (see discussion in Reference 6). Regardless, the data are still worth considering, and support at least the $\Delta\gamma_{max}/\Delta\gamma_{ss}$ limit.

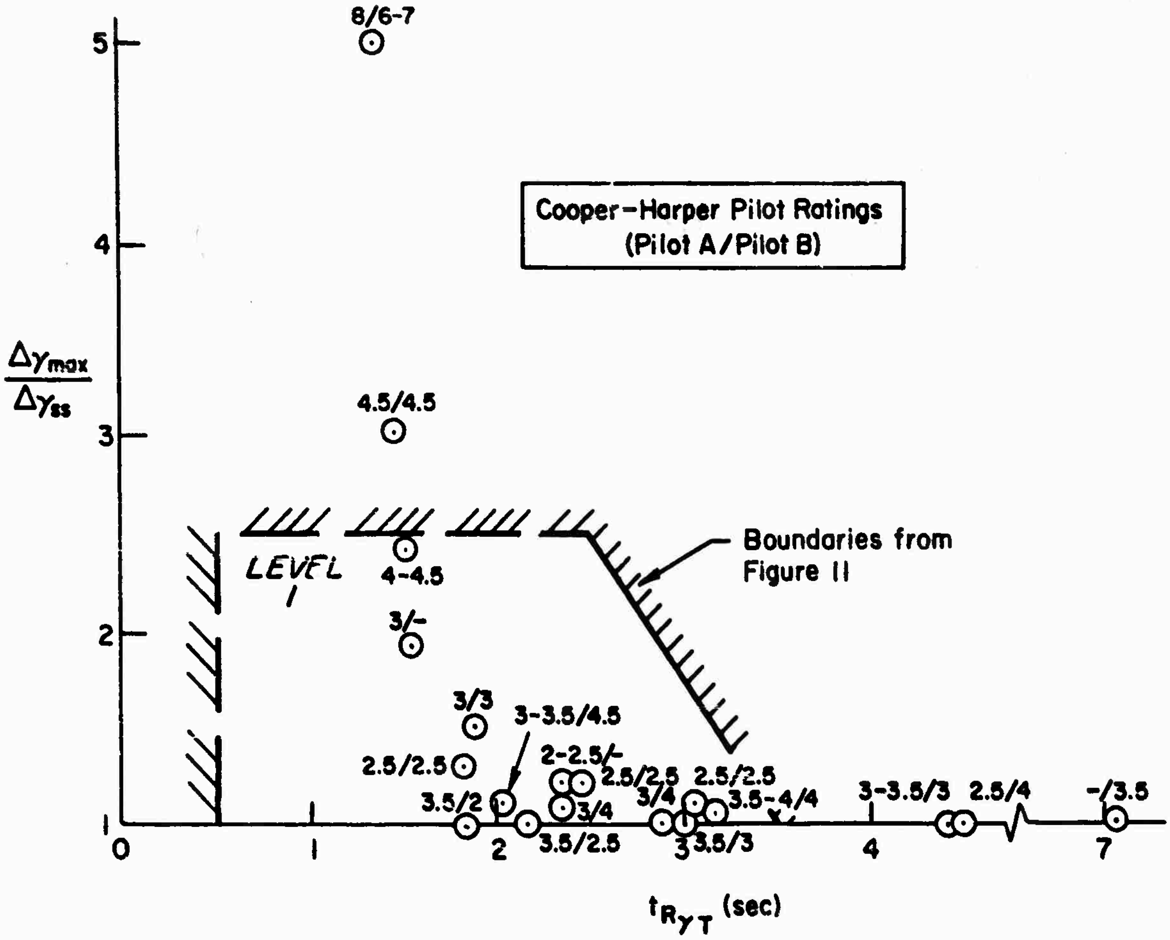


Figure 12. Pilot Ratings for ILS Tracking Task with Simulation of Augmentor Wing; Calm Air (Reference 15)

Figures 11 and 12 lack sufficient data to support a Level 2 limit in either rise time or overshoot, and thus there is no such limit in the Figure 6 requirement.

b. Flare and Landing

There is a substantial amount of data that indicates that the use of throttle to flare can result in Level 1 handling qualities. For example, all of the data in Figure 13 are for configurations where the pilots noted that flaring with pitch attitude was not possible (see Reference 3 for more detail). There is somewhat stronger support for the Level 1 limit here than in the approach flight condition. This is probably attributable to the fact that there was less time to correct for responses that were sluggish or had overshoot in the flare maneuver; i.e., landings require more precision than approaches. This important result has been observed during all approach and landing experiments, STOL and CTOL, and is discussed in detail in Reference 6. The ratings suggest much less tolerance for overshoot, as one would expect. There is insufficient data to define a Level 2 boundary.

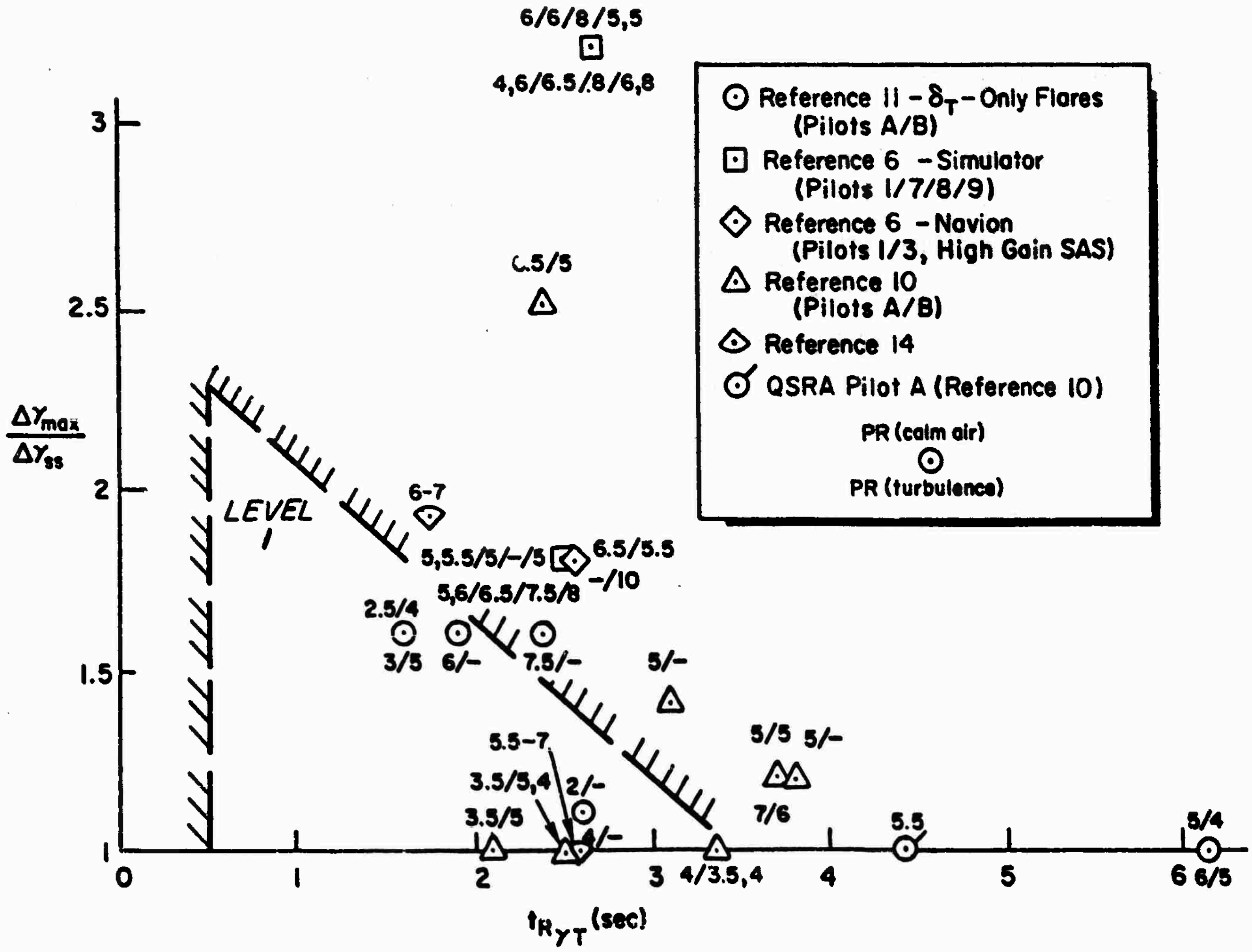


Figure 13. Pilot Rating Data for Flare and Landing with Throttle (from Reference 3)

SECTION IV

DEVELOPMENT OF PRECISION LANDING CRITERIA

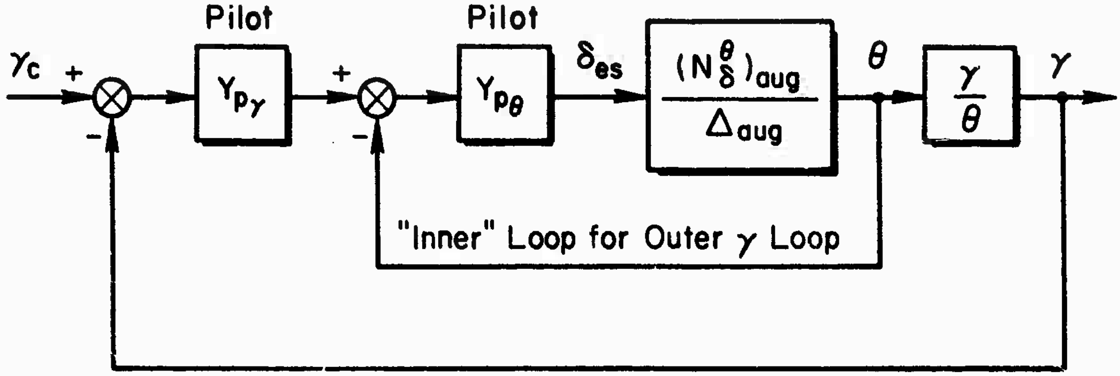
A. DATA SOURCES

The data utilized to develop and substantiate the proposed requirements (Section III-A) consisted of a recent in-flight simulation of flared landings using the USAF/Calspan Total In-Flight Simulator (TIFS, Reference 2), and a moving-base simulation of STOL landings conducted on the USAF Large Amplitude Multimode Research Simulator (LAMARS) (see Appendix A). The data from a fixed-base simulation of fighter STOL landings (Reference 17) were also considered, but not analyzed extensively as the details of the dynamics of the configurations (transfer functions) were not available. A second TIFS approach and landing study was conducted as a follow-on to the Reference 2 experiment. These data are discussed only briefly as they were unofficially received (in raw and incomplete form) just as this report was being completed.

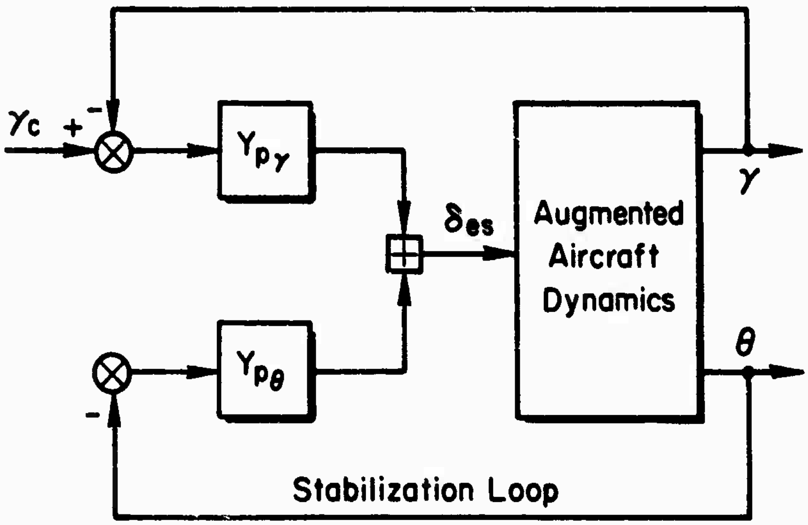
B. PILOT-VEHICLE ANALYSIS

In this section, the well-developed theories of pilot-vehicle analysis and the associated crossover model are applied to formulate potential parameters to predict handling qualities for precision landings with pitch attitude. Piloted control of flight path has been studied extensively using both the series and parallel pilot models shown in Figure 14. The detailed characteristics of attitude and flight path control for series and parallel pilot models is analyzed in Reference 18, which shows that, from a purely dynamic standpoint, the series structure is preferred if lead is required to stabilize pitch attitude, and the parallel structure is best if lag is utilized by the pilot in the attitude loop. Some other factors that determine which structure the pilot actually adopts are:

- the required bandwidths of the attitude and path loops. If $\omega_{BW_\theta} \gg \omega_{BW_\gamma}$ the pilot is more likely to adopt a series strategy than if $\omega_{BW_\theta} \doteq \omega_{BW_\gamma}$.



Series Pilot Model



Parallel Pilot Model

Figure 14. Series and Parallel Forms of the Pilot Model for Piloted Path Control

- the pitch attitude augmentation, e.g., the amount of stabilization that must be supplied by the pilot. If attitude is inherently well stabilized, the pilot may be prone to closing the γ loop directly, with only intermittent attention to attitude control.

- the flight path response to longitudinal controller. If the γ/δ response does not require significant equalization, the pilot will be more prone to controlling γ directly (parallel) rather than through θ (series).

The key parameters that govern the flying qualities for approach and landing depend, to some extent, on which form of the model is assumed. Therefore, the approach taken herein has been to attempt correlations with the pilot rating data with variables that derive from both the series and parallel forms of the pilot model. Before proceeding with these correlations, it is necessary to develop the generic characteristics of attitude and flight path control for the most common types of attitude augmentation, i.e.,

- Conventional response with improved dynamics, i.e., angle-of-attack plus pitch rate feedback.

- Rate command/attitude hold (RCAH).

- Attitude command/attitude hold (ACAH).

Conventional attitude and flight path response characteristics are obtained when angle-of-attack and pitch rate are employed as feedbacks. The pitch attitude-to-longitudinal controller transfer function for such conventional responses is given as (see References 19):

$$\frac{\theta}{\delta_{es}} = \frac{M_{\delta_{es}}\left(1/T_{\theta_1}\right)\left(1/T_{\theta_2}\right)}{[\zeta_p\omega_p][\zeta_{sp}\omega_{sp}]}^{*}$$

---

*Notation: $(1/T) \rightarrow (s + 1/T)$; $[\zeta\omega] \rightarrow [s^2 + 2\zeta\omega s + \omega^2]$

Virtually all existing fly-by-wire aircraft (for example the F-16, Space Shuttle, X-29) utilize a rate-command-type augmentation with a parallel integrator in the forward loop, which provides an attitude signal to supply the required stiffness, and attitude hold. A block diagram and generic root locus plot for a statically unstable aircraft, showing the effect of increasing the loop gain on the closed-loop roots for RCAH augmentation, is given in Figure 15. When the gains are sufficiently high, so that the poles effectively drive into, and therefore cancel, the zeros, the aircraft is referred to as being superaugmented (see Reference 20). It is noteworthy that the dominant second-order pole (ω') circles the $1/T_q$ zero so that the pitch attitude bandwidth is set by $1/T_q$.

Attitude command/attitude hold (ACAH) represents a viable, albeit less popular, augmentation scheme. The generic system survey characteristics of the loop closure for ACAH are illustrated in Figure 16.

The angle-of-attack and flight path angle responses resulting from a change in pitch attitude are well approximated as follows:

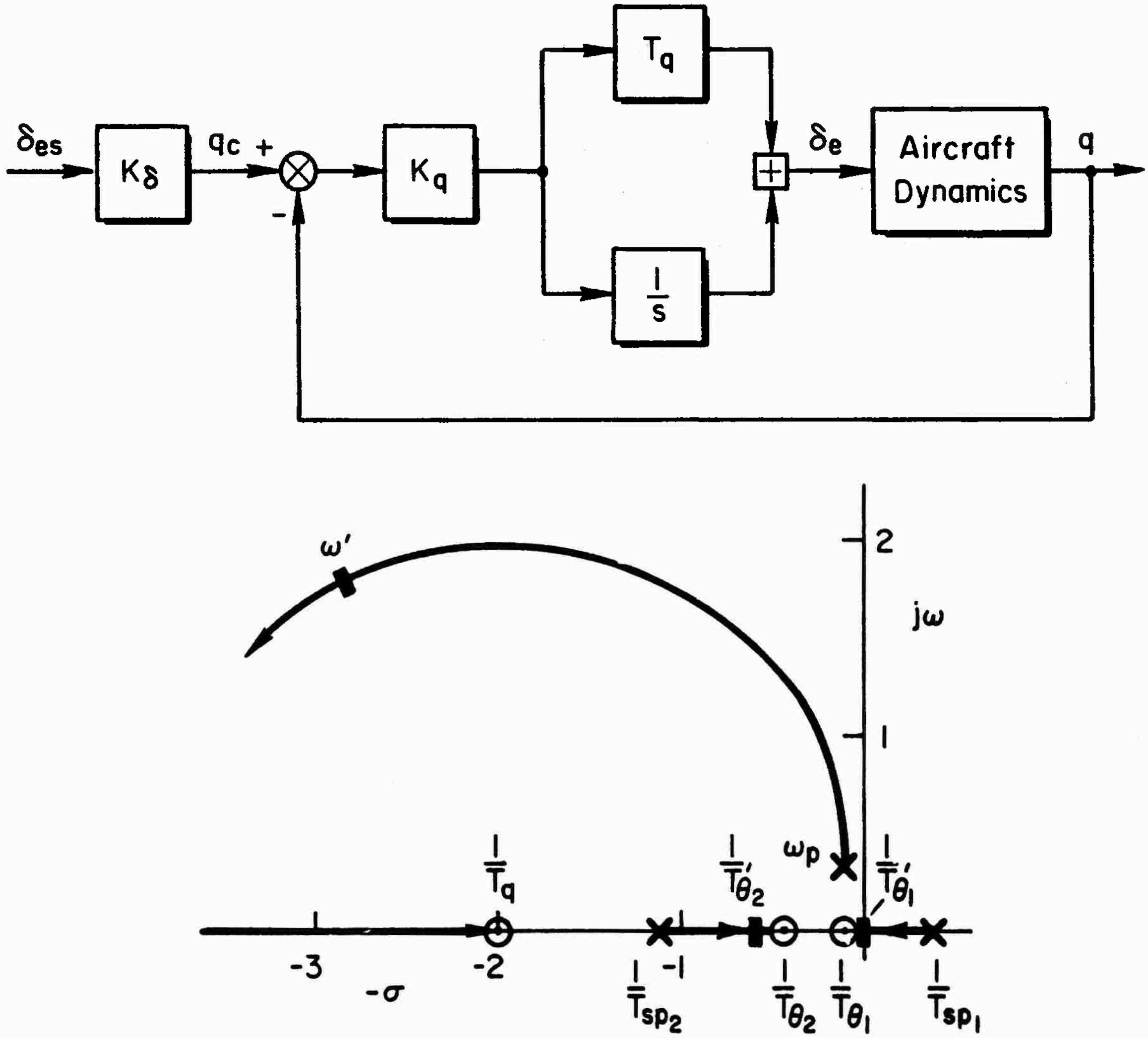
$$\frac{\alpha}{\theta} \doteq \frac{[\zeta_p \omega_p]}{(1/T_{\theta_1})(1/T_{\theta_2})}$$

$$\frac{\gamma}{\theta} \doteq \frac{Z_{\delta_e}(1/T_{\gamma_1})(1/T_{\gamma_2})(1/T_{\gamma_3})}{U_o M_\delta (1/T_{\theta_1})(1/T_{\theta_2})} \doteq \frac{1}{(1/T_{\theta_2})}{}^{*}$$

Using these approximations the θ/δ_{es}, γ/δ_{es}, and α/δ_{es} transfer functions can be approximated with the results shown in Table 2. The generic characteristics of the frequency and time responses of attitude,

---

*The effect of $1/T_{\gamma_2}$ and $1/T_{\gamma_3}$ accounts for Z_{δ_e}. This can be an important effect and is ignored here only to allow a comparison of different response-types. (See Section IV-D for a more detailed discussion.)



▮ Denotes closed loop roots – labeled as prime

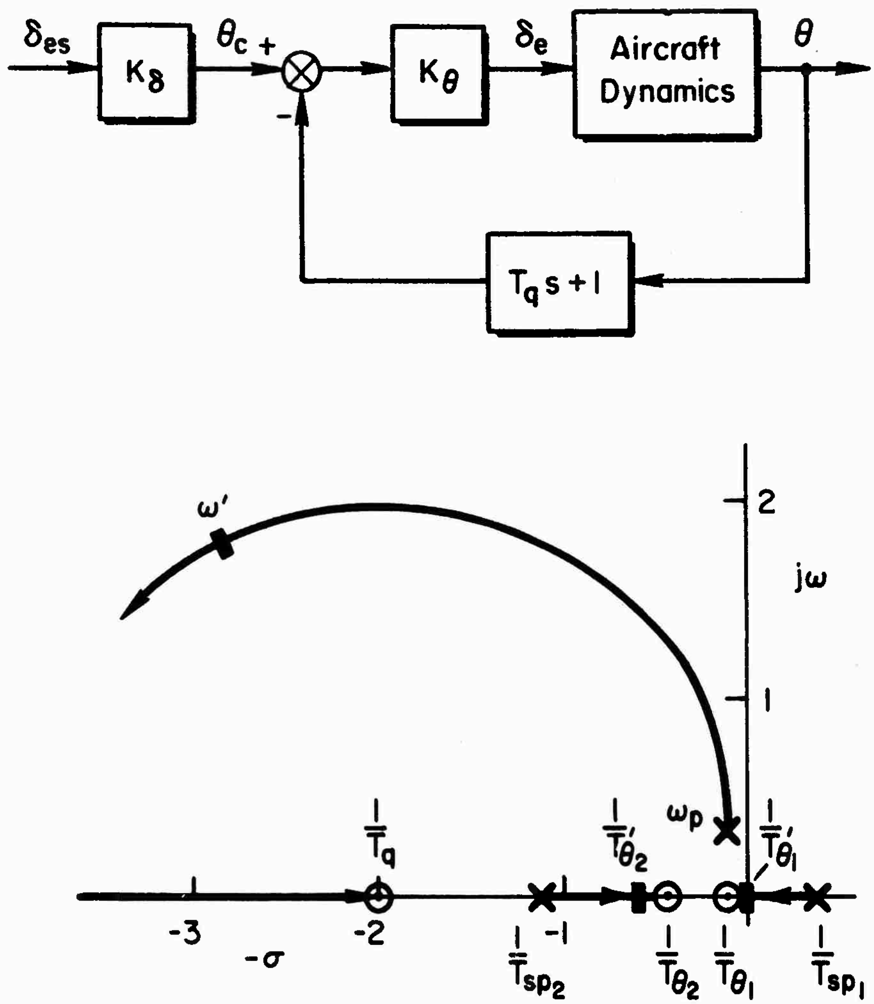
Roots on real axis are labeled as prime of zero they are driving into

$$\frac{q}{q_c} = \frac{K_q T_q M_{\delta_e} (1/T_{\theta_1})(1/T_{\theta_2})(1/T_q)}{(1/T'_{\theta_1})(1/T'_{\theta_2})[\zeta' \, \omega']} \doteq \frac{K_q T_q M_{\delta_e} (1/T_q)}{[\zeta' \, \omega']}$$

Shorthand Notation: $(1/T) \Rightarrow (s + 1/T)$

$$[\zeta \, \omega] \Rightarrow [s^2 + 2\zeta\omega s + \omega^2]$$

Figure 15. Generic Rate Command/Attitude Hold (RCAH) Loop Closure Characteristics



$$\frac{\theta}{\theta_c} = \frac{K_\theta M_{\delta_e}(1/T_{\theta_1})(1/T_{\theta_2})}{(1/T'_{\theta_1})(1/T'_{\theta_2})[\zeta'\omega']} \doteq \frac{K_\theta M_{\delta_e}}{[\zeta'\omega']}$$

Figure 16. Generic Attitude Command/Attitude Hold (ACAH) Characteristics

TABLE 2. APPROXIMATIONS FOR ATTITUDE, ANGLE-OF-ATTACK, AND FLIGHT PATH ANGLE TO PITCH CONTROL INPUT

Pitch Attitude	$\frac{\theta}{\delta_{es}}$	$\frac{\alpha}{\delta_{es}}$	$\frac{\gamma}{\delta_{es}}$
Conventional	$\frac{M_{\delta_e}(1/T_{\theta_1})(1/T_{\theta_2})}{[\zeta_p\omega_p][\zeta_{sp}\omega_{sp}]}$	$\frac{M_{\delta_e}}{[\zeta_{sp}\omega_{sp}]}$	$\frac{M_{\delta_e}(1/T_{\theta_1})}{[\zeta_p\omega_p][\zeta_{sp}\omega_{sp}]}$
Rate Command/ Attitude Hold (RCAH)	$\frac{K_q M_{\delta_e}(1/T_q)}{(0)[\zeta'\omega']}$	$\frac{K_q M_{\delta_e}(1/T_q)[\zeta_p\omega_p]}{(0)(1/T_{\theta_1})(1/T_{\theta_2})[\zeta'\omega']}$	$\frac{K_q M_{\delta_e} 1/T_{\theta_2}(1/T_q)}{(0)(1/T_{\theta_2})[\zeta'\omega']}$
Attitude Command/ Attitude Hold (ACAH)	$\frac{K_\theta M_{\delta_e}}{[\zeta'\omega']}$	$\frac{K_\theta M_{\delta_e}[\zeta_p\omega_p]}{(1/T_{\theta_1})(1/T_{\theta_2})[\zeta'\omega']}$	$\frac{K_\theta M_{\delta_e} 1/T_{\theta_2}}{(1/T_{\theta_2})[\zeta'\omega']}$

Note: $(1/T) \Rightarrow (s + 1/T)$, $[\zeta\omega] \Rightarrow [s^2 + 2\zeta\omega s + \omega^2]$

flight path angle, and angle-of-attack for each of the augmentation schemes discussed above are presented in Figure 17.

The following observations can be made from Figure 17 regarding flight path control with pitch attitude.

- The slopes of the γ and θ frequency response asymptotes are equal below $1/T_{\theta_2}$, and differ by 20 dB/decade (γ lags θ) above $1/T_{\theta_2}$ for all attitude augmentation schemes, i.e., $\gamma/\theta \doteq 1/(T_{\theta_2}s + 1)$.

- The bandwidth of θ/δ_{es} depends on ω' and $1/T_{\theta_2}$ (or $1/T_q$ for RCAH).

- The bandwidth of γ/δ_{es} depends on:

  -- ω_{sp} for conventional response-type (Figure 17a).

  -- ω' and $(1/T_q - 1/T_{\theta_2})$ for RCAH (Figure 17b). Note that γ/δ_{es} is K/s^2 between $1/T_{\theta_2}$ and $1/T_q$.

  -- ω' and $1/T_{\theta_2}$ for ACAH (Figure 17c).

- The angle-of-attack response to a step pitch controller input looks like:

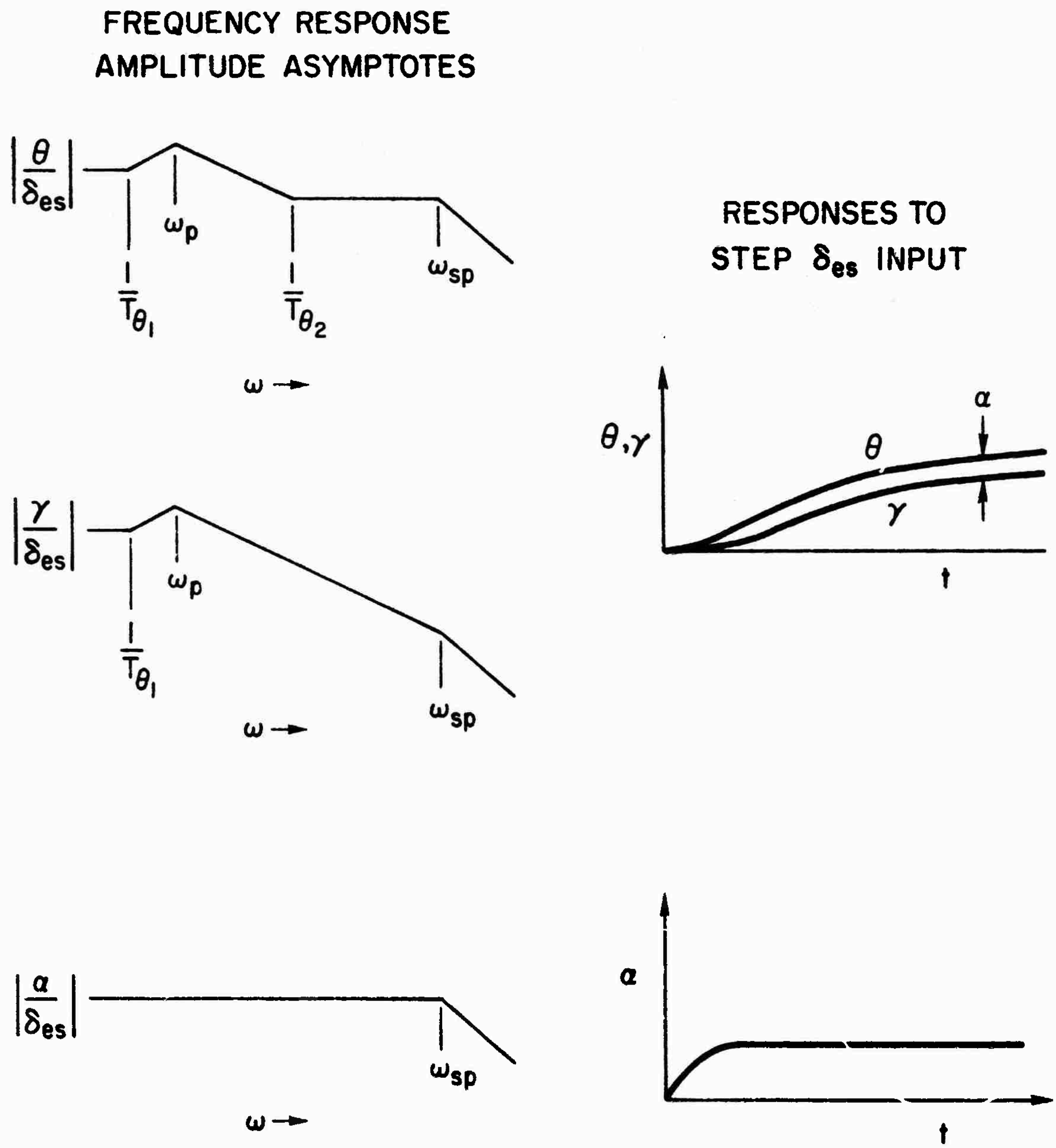
  -- a step for conventional response-types.

  -- a step for RCAH response-types when $1/T_{\theta_2} \doteq 1/T_q$.

  -- a ramp for RCAH response-types when $1/T_{\theta_2} << 1/T_q$.

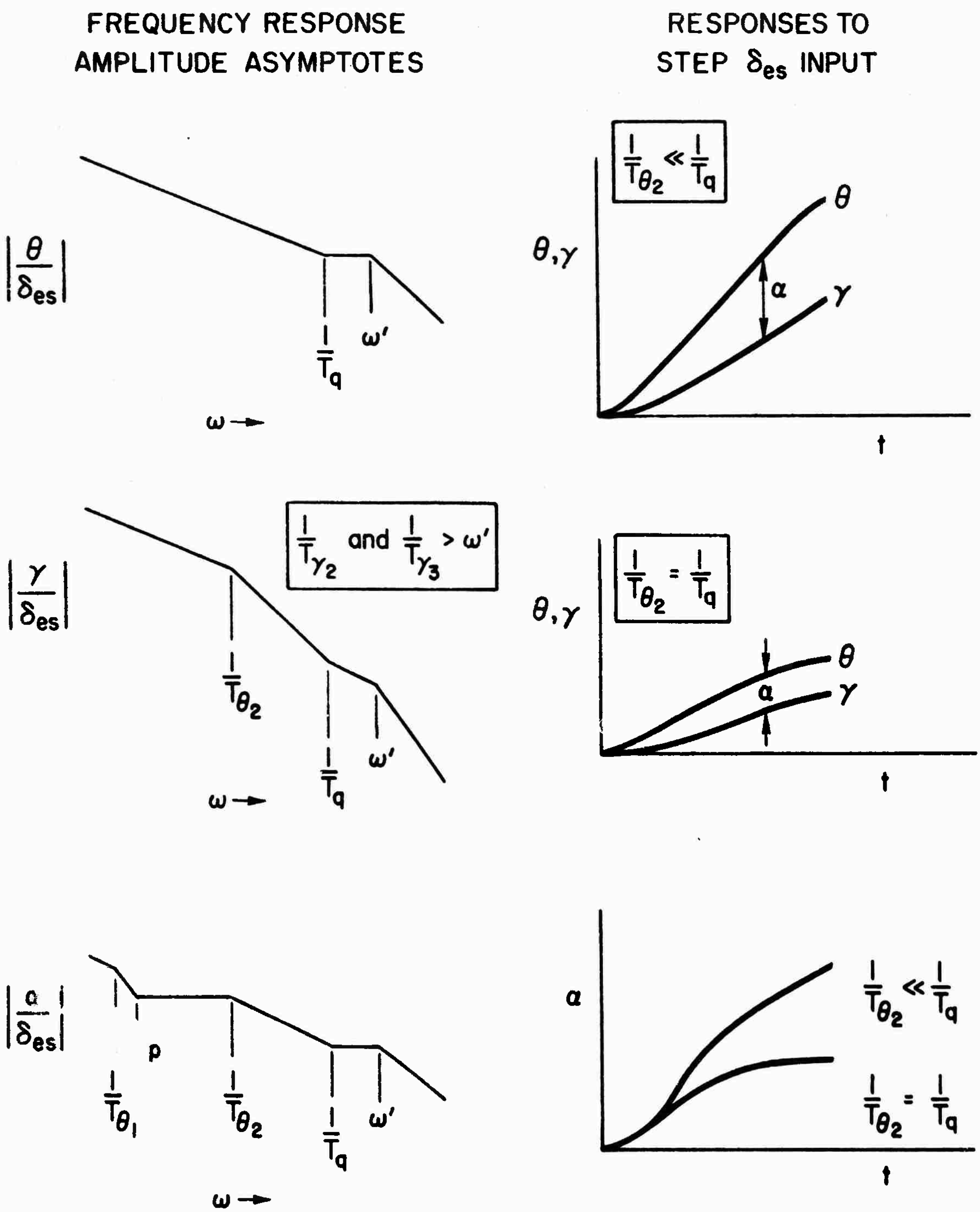
  -- a step with some initial overshoot for ACAH response-types.

The attitude and altitude bandwidths (ω_{BW_θ} and ω_{BW_γ}) used in this report are based on the definition established in References 1 and 3. That is, the bandwidth is defined as the frequency at which the phase margin is 45 degrees or the gain margin is 6 dB, whichever is less, see Figure 2. The basis for this metric is that it is representative of the maximum frequency (or equivalently maximum gain) at which the pilot can close the loop without threatening stability, with zero lead equalization. This definition of bandwidth, when applied to pitch attitude, correlates the pilot rating data very well in References 1 and 3, but



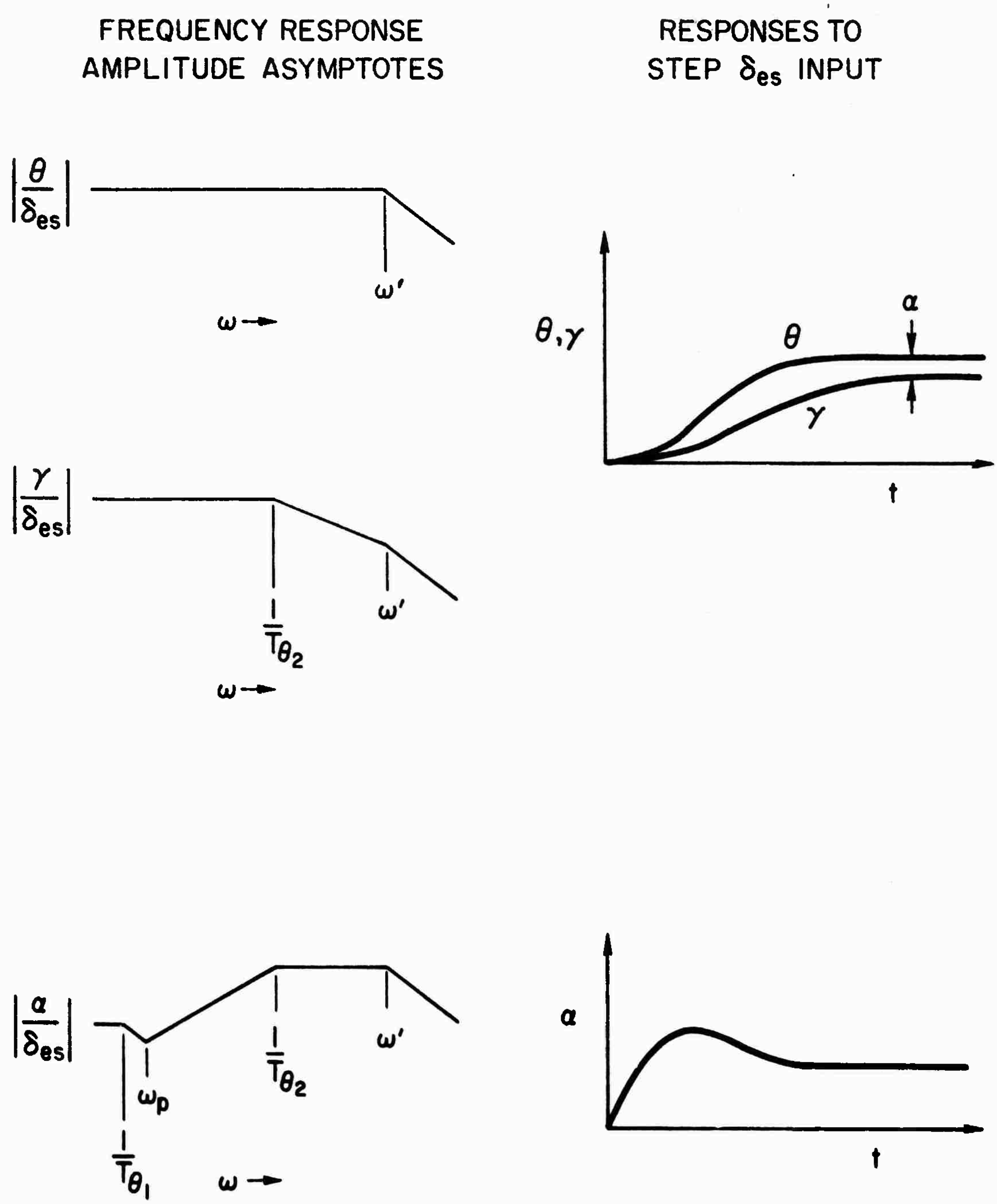
a) Conventional Airplane Response (equivalent systems valid for this response-types)

Figure 17. Generic Characteristics of Common Airplane Response Types



b) Rate Command/Attitude Hold (RCAH)

Figure 17. (Continued)



c) Attitude Command / Attitude Hold (ACAH)

Figure 17. (Concluded)

was shown to be somewhat unsuccessful in the flared landing study of Reference 2. Reference 2 represents the first set of flight test landing data where the attitude and flight path responses were systematically varied. In Reference 1, the flight path response characteristics ($1/T_{\theta_2}$) were unchanged for each set of data so that pitch attitude bandwidth correlated the data from any one experiment. Not surprisingly, it is necessary to account for the bandwidth of the attitude and altitude loops to correlate data in experiments where both of these variables are varied, such as Reference 2. This approach was taken in developing handling qualities criteria for STOL aircraft in Reference 3, where the parameter $\left(1/T_{\theta_2}\right)_{eff}$ was suggested as representative of the path control bandwidth based on the series pilot model (Figure 14). Both attitude and path control were taken into account in Reference 21 (an analysis of the Reference 2 data) where a constant 25° pilot attitude lead equalization was assumed to form the inner loop closure, and the outer loop bandwidth (Neal-Smith definition) was used as a correlating parameter with good results.

Based on the generic Bode asymptotes in Figure 17, and the series and parallel pilot models in Figure 14, the following parameters were picked as potential handling qualities criteria for precision flare and landing.

- ω_{BW_θ} -- This parameter defines the bandwidth of the attitude loop (see Figure 2) and has a direct influence on the bandwidth of the path control loop for the series or parallel pilot model (i.e., is a strong function of ω').

- $1/T_{\theta_2}$ -- Defines the lag between attitude and flight path as shown by the following approximation (assuming $M_{\delta_{es}}$ is large compared to $Z_{\delta_{es}}$):

$$\frac{\gamma}{\theta} \doteq \frac{1}{T_{\theta_2}s + 1}$$

  For cases where the above approximation does not hold, an effective value of $1/T_{\theta_2}$ was defined in Reference 3 as the frequency where γ lags θ by

45 deg, $(1/T_{\theta_2})_{eff}$. This was illustrated in Figure 3, taken from Reference 3.

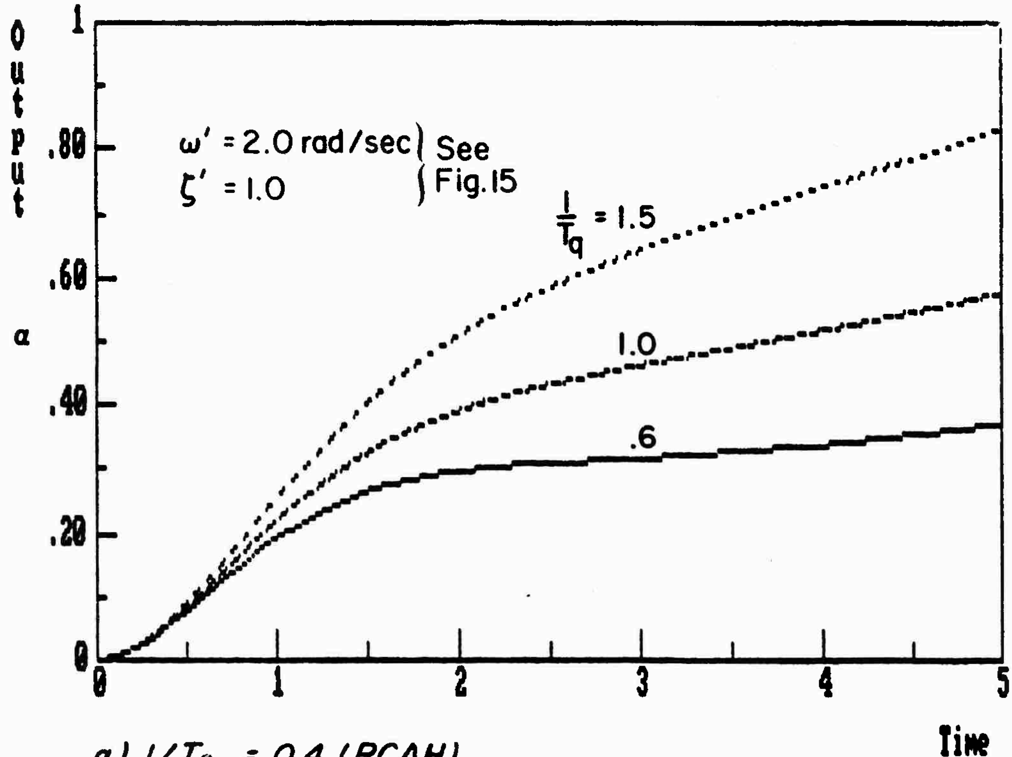
- ω_{BW_γ} -- Defines the bandwidth (Figure 8 definition) of the flight path response to longitudinal controller inputs. This parameter is most physically significant when the parallel pilot model is employed, i.e., pilot controls γ directly with δ_{es} rather than through attitude, see Figure 14.

- $(1/T_q - 1/T_{\theta_2})$ -- Defines the region where γ/δ_{es} is K/s^2 if $1/T_{\theta_2} < 1/T_q$. Based on the crossover model defined in pilot-vehicle analysis theory (see for example Reference 22), the pilot equalization will consist of a lead at $1/T_{\theta_2}$ and a lag at $1/T_q$ where the quasi-linear pilot model assumed is:

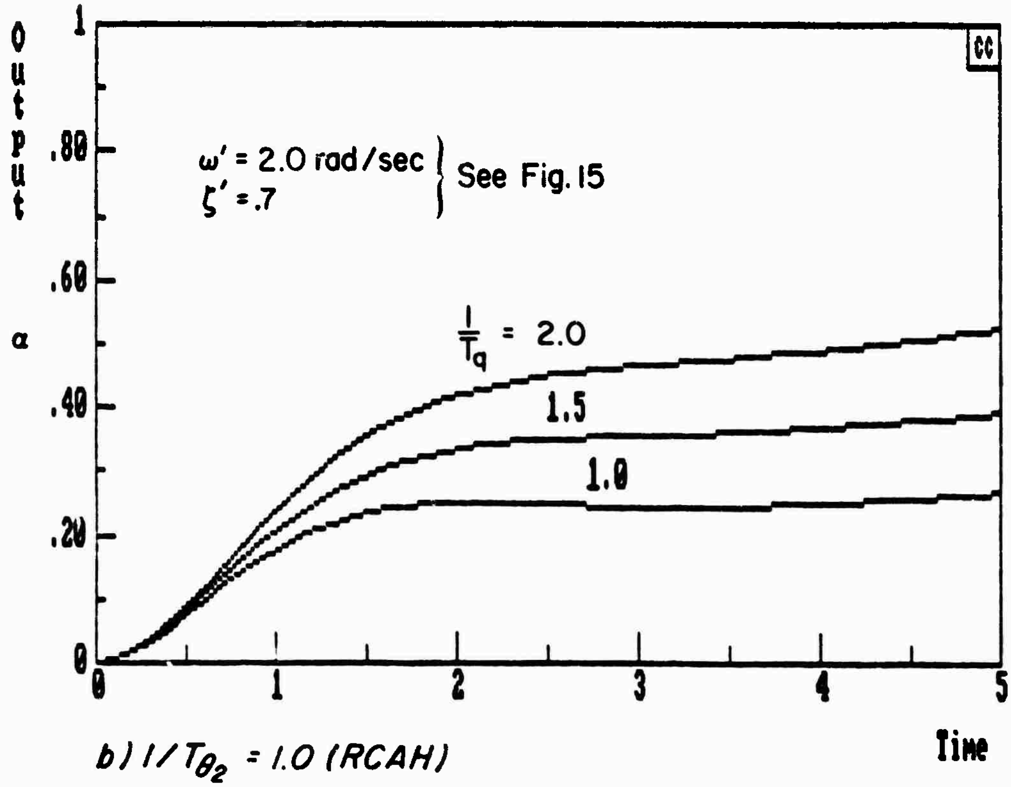
$$Y_p = K_p e^{-\tau_p s} \frac{(T_L s + 1)}{(T_I s + 1)}$$

Reference 22 indicates that the pilot will always equalize so that $\gamma/\delta_{es} = K/s$, and if this requires a lead zero $(1/T_L)$ at less than 1 sec, Level 2 pilot ratings are expected to occur.

- Shape of the α response -- The existence of a region of K/s^2 in the γ/δ_{es} response corresponds to a region of K/s in the α/δ_{es} response (see Figure 17b). In the time domain, this represents a monotonically increasing response to a step δ_{es} input. Therefore, if the angle-of-attack ramps in response to a step longitudinal controller input, a significant region of K/s^2 in the γ/δ_{es} response is indicated; whereas if α responds as a step, γ/δ_{es} has the desired K/s shape in the region of piloted crossover. These characteristics are shown generically in Figure 18 for several values of $1/T_q$ and $1/T_{\theta_2}$. The long-term ramping is due to the phugoid and is of no consequence unless the phugoid frequency is unusually high. If $1/T_{\theta_2}$ is large (say greater than 1.0), the region of K/s^2 will occur above the crossover region for path control (about 0.3 to 1.0 rad/sec) and will be of little consequence. Interestingly, the short-term α response also looks like a step for such cases regardless of $1/T_q$ (e.g., Figure 18b). In summary, a step-like



a) $1/T_{\theta_2}$ = 0.4 (RCAH)



b) $1/T_{\theta_2}$ = 1.0 (RCAH)

Figure 18. Generic Angle-of-Attack Responses

short-term α response appears to be a good indicator that γ/δ_{es} is the desired K/s in the region of piloted crossover for flight-path control.

C. CORRELATIONS WITH PILOT RATING DATA

The physical implication of the series pilot model is that the pilot uses pitch attitude, θ, as a controller for flight path angle, γ, Figure 14. On this basis, it would be expected that the handling qualities for precision flight path control tasks would depend on good attitude control, θ/δ_{es}, and a rapid path response to changes in pitch attitude, γ/θ. The STOL handling qualities criteria proposed in Reference 3 are based on this premise and involve limits on the pitch attitude bandwidth, ω_{BW_θ}, and effective flight path lag, $\left(1/T_{\theta_2}\right)_{eff}$. The pilot rating data from the flared landing experiment performed on the TIFS (Reference 2) is plotted on a grid of ω_{BW_θ} vs. $\left(1/T_{\theta_2}\right)_{eff}$ in Figure 19. These parameters do not provide an obvious separation between regions of good and bad pilot ratings. It is notable that the cases with a monotonically increasing response to a step δ_{es} (filled symbols) are consistently rated poorly, a clue that the pilot is interested in the γ/δ_{es} response without an inner attitude loop closure. Recall that γ/δ_{es} is K/s^2 in the region of piloted crossover if the short-term α response to a step δ_{es} is monotonically increasing during the first five seconds. The angle-of-attack responses for all the Reference 2 configurations are sketched in Figure 20.

Based on the poor correlation with $\left(1/T_{\theta_2}\right)_{eff}$ and noting that the pilot must be able to quickly stabilize pitch attitude (i.e., both ω_{BW_γ} <u>and</u> ω_{BW_θ} are important), the pilot ratings were plotted on a grid of ω_{BW_γ} vs. ω_{BW_θ} with the results shown in Figure 21. With only a few exceptions, these parameters separate the Level 1 and Level 2 configurations. Other important observations from Figure 21 are:

- ω_{BW_γ} increases monotonically with ω_{BW_θ} for cases where γ/δ_{es} is K/s in the region of piloted crossover (0.3 to 1 rad/sec) (open symbols). All of these cases have a short-term step α response to a step δ_{es} input (see Figure 20).

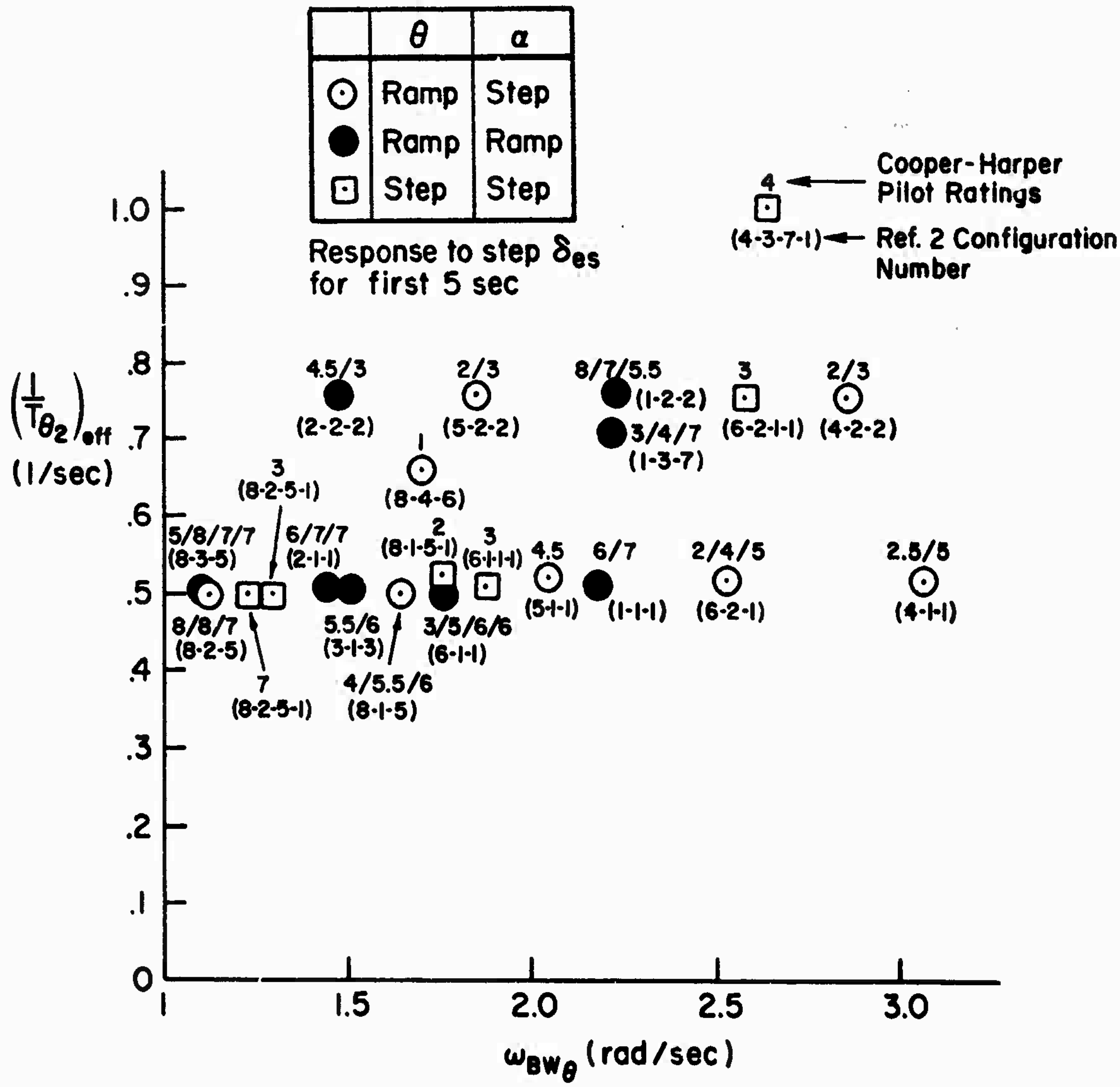


Figure 19. Pilot Rating Correlations with $(1/T_{\theta_2})_{eff}$ and ω_{BW_θ}

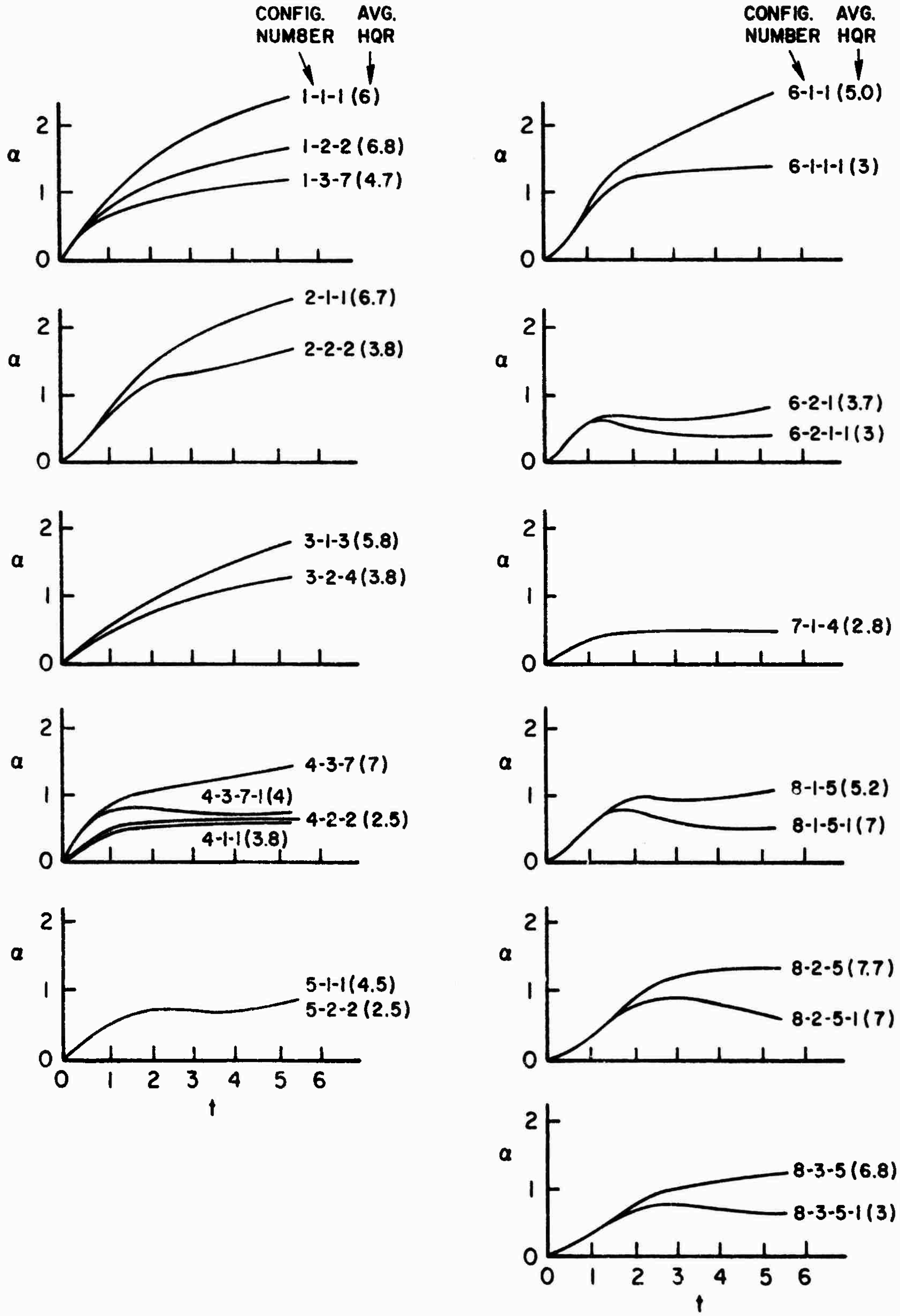


Figure 20. Angle-of-Attack Responses to Step δ_{es} from Reference 2

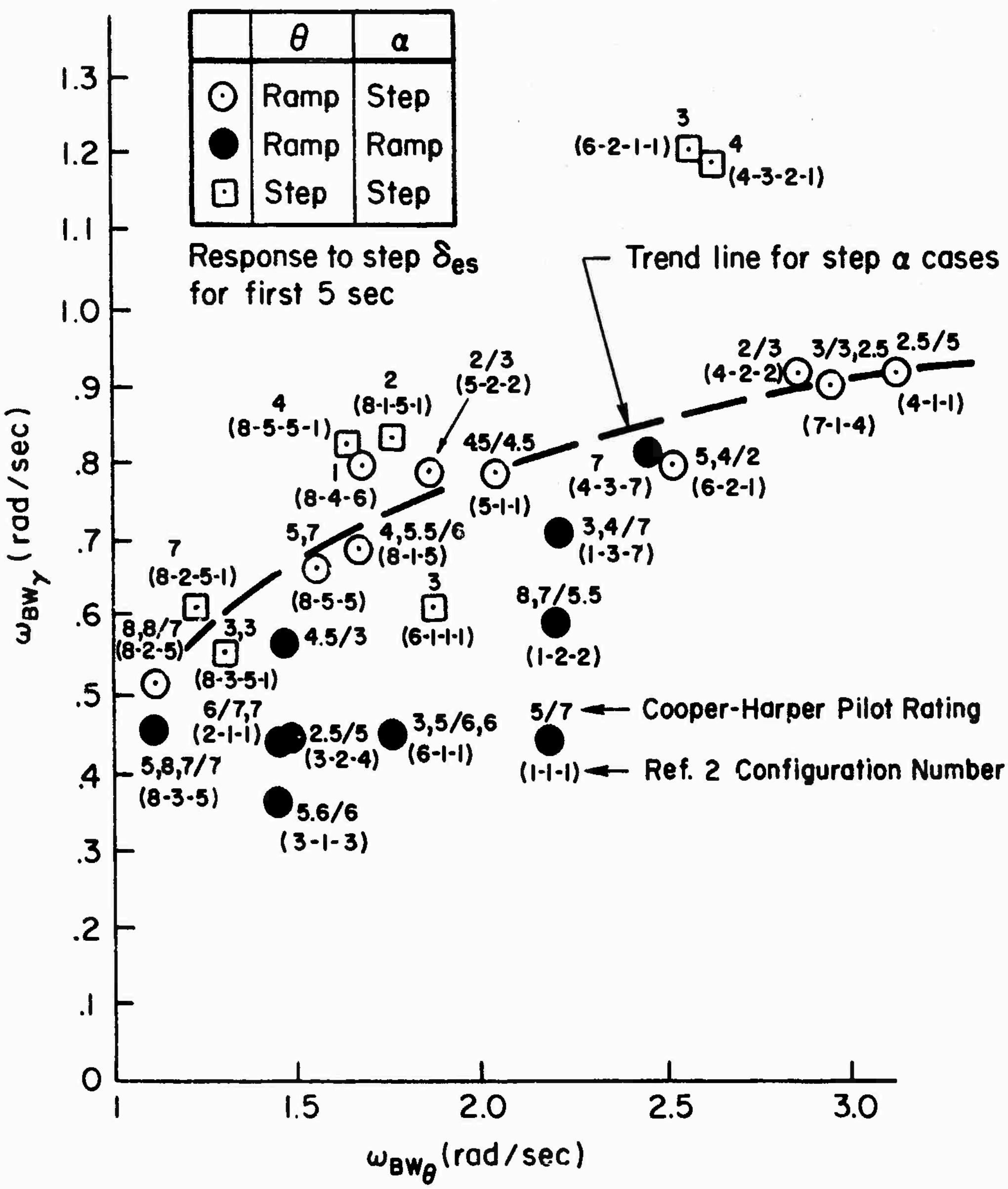


Figure 21. Pilot Rating Correlations with $(1/T_{\theta_2})_{eff}$ and ω_{BW_θ}
Reference 1 Flared Landing Experiment

- Cases with a K/s^2 frequency response in the region of piloted crossover (solid symbols) exhibit lower ω_{BW_γ} and degraded pilot ratings. All of these cases have a short-term ramp-like (or monotonically increasing) response to a step δ_{es} input.

- Changing from RCAH to ACAH (square symbols) at essentially constant ω_{BW_θ} results in an increase in ω_{BW_γ} (note that adding a fourth "one" to the configuration number designates an ACAH response-type, i.e., configuration 6-2-1 is RCAH and 6-2-1-1 is ACAH). Except for one case with a very low ω_{BW_θ}, all the ACAH cases are rated either Level 1, or barely Level 2 (HQR = 4).

A moving-base simulation experiment was conducted by the USAF Flight Dynamics Lab (FIGC) on the Large Amplitude Multimode Research Simulator (LAMARS) in direct support of the research reported herein (the configurations were selected from the test plan in Section V). The simulation task consisted of approaches to a 130-ft by 1500-ft runway with an approach speed of 130 kts -- representative of a nonpowered-lift fighter STOL concept. The cockpit resembled a fighter aircraft, and the pilot was supplied with a head-up display (HUD), which included an inertial velocity vector symbol (i.e., flight path angle was displayed directly to the pilot). The pilots were instructed to minimize the flare during landing and the performance limits for longitudinal touchdown location were plus or minus 75 ft (desired) and plus 150 ft or minus 100 ft (adequate). The resulting pilot rating data are plotted on a grid of ω_{BW_θ} vs. ω_{BW_γ} in Figure 22. The results agree quite well with the Reference 2 data in Figure 21, and all of the conclusions drawn above are equally applicable here.

Once a K/s response in γ/δ_{es} is assured (i.e., α is essentially a step for the first 5 sec following a step longitudinal controller input) for the data examined in Reference 2 and Appendix A, the pilot rating data correlate quite well with pitch attitude bandwidth, ω_{BW_θ}, as illustrated in Figures 23b and 23c where all such cases are plotted on a grid of ω_{BW_θ} vs. pilot rating.

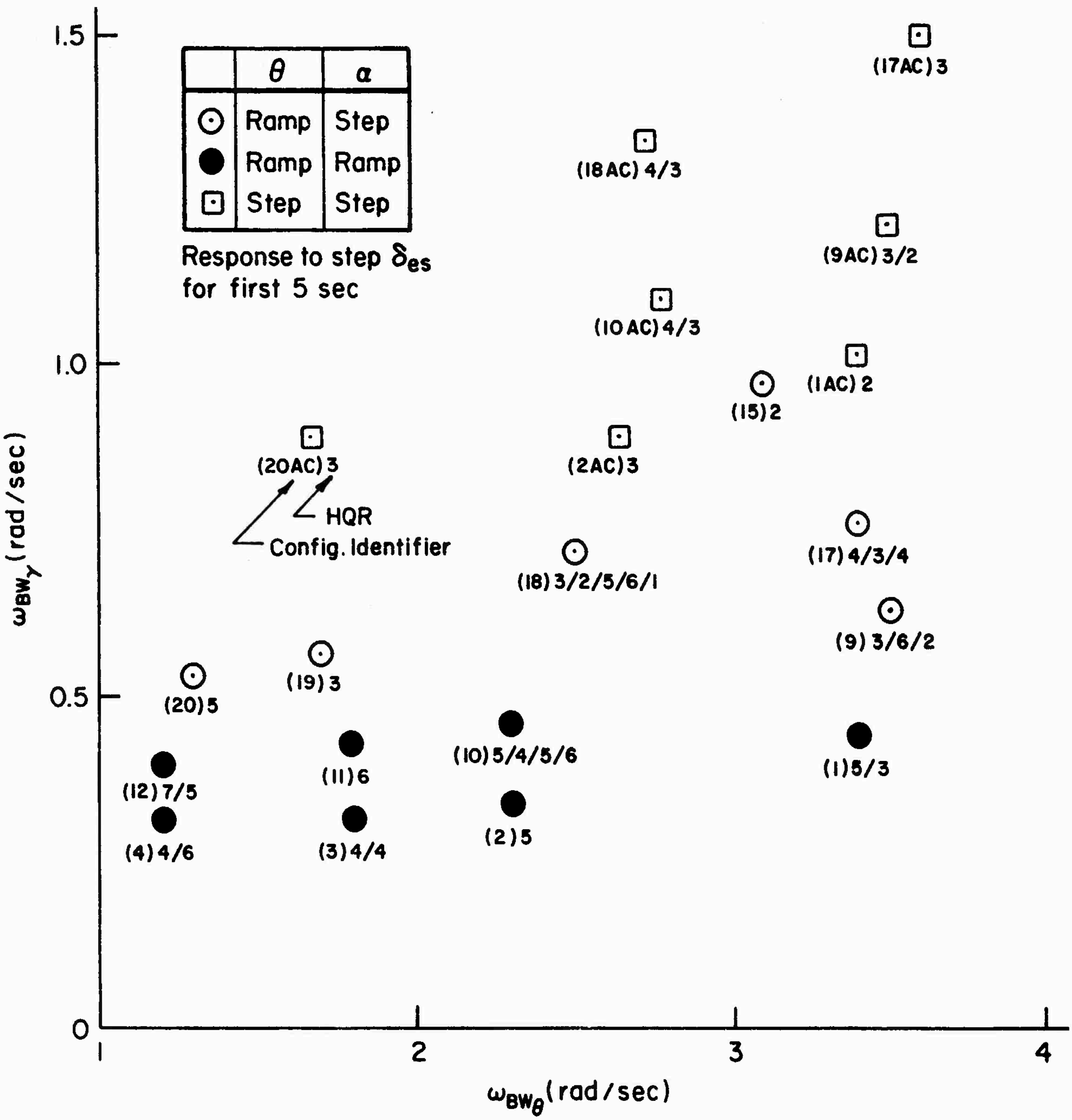


Figure 22. Fighter STOL Simulation Data (LAMARS Appendix A)

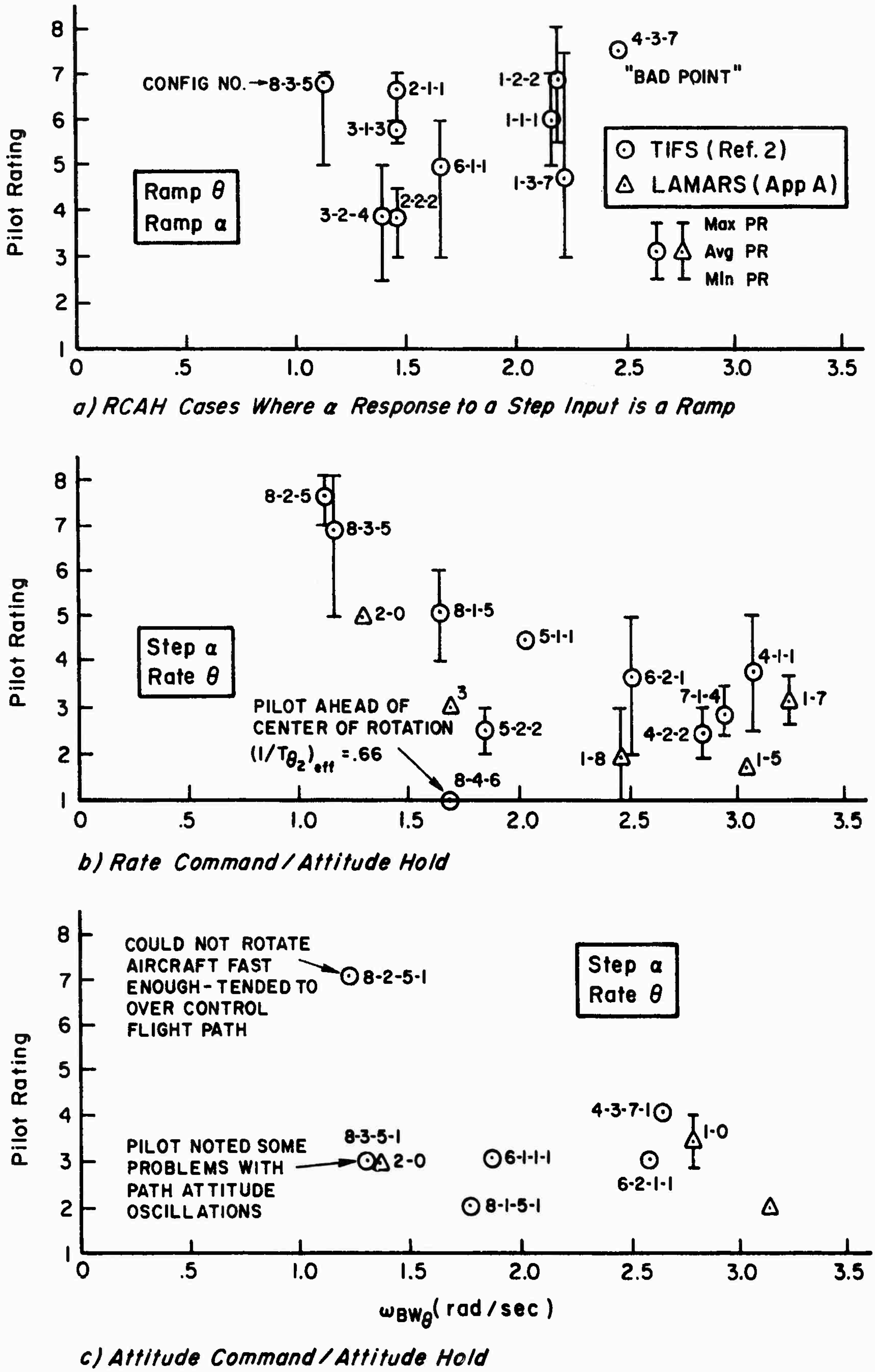


Figure 23. Correlation of ω_{BW_θ} with Pilot Rating

While the pilot rating levels are quite well separated in Figures 21, 22, and 23, there are some anomalous points which are discussed below.

- Configuration 4-3-7 (from Reference 2) was rated a 7 by Pilot B, and falls in a region of pilot ratings of between 2 and 5 in Figure 21 ($\omega_{BW_\theta} \doteq 2.5$ rad/sec, $\omega_{BW_\gamma} \doteq 0.8$ rad/sec.) Pilot B also rated configuration 1-3-7 (below 4-3-7) a 7. These configurations are very similar in that they only differ by a lead/lag prefilter designed to cancel the effects of the $1/T_q$ and $1/T_{\theta_2}$ separation (effectively eliminating the K/s^2 region in γ/δ_{es}). Since $1/T_{\theta_2} = 1.0$ and $1/T_q = 2.0$ we would expect very little effect due to this prefilter. This is supported by a strong similarity in the θ, α, and γ time histories as well as close values of ω_{BW_θ} and ω_{BW_γ}. It is suggested in Reference 2 that configuration 4-3-7 be considered an anomalous point as it "falls way out in left field" with all criteria attempted. It would seem that either both of these evaluations by Pilot B are valid, or both are invalid. Since both of these configurations have K/s^2 asymptotes in γ/δ_{es}, between 1.0 and 2.0 rad/sec ($1/T_{\theta_2}$ and $1/T_q$), it is suspected that Pilot B utilizes a more aggressive path tracking technique in the flare than that of Pilot A (who rated 1-3-7 a 3 and 4 and did not fly 4-3-7). Based on this interpretation, the final criterion should require a K/s asymptote in γ/δ_{es} out to 1.5, or even 2 rad/sec to accommodate pilots such as Pilot B. Interestingly, both of these configurations exhibit a distinctly non-step-like short-term α response to a step δ_{es} input (see Figure 20).

- Pilot A's evalution of configuration 8-2-5-1 ($\omega_{BW_\theta} \doteq 1/2$ rad/sec, $\omega_{BW_\gamma} \doteq 0.6$ rad/sec on Figure 21) (HQR=7) was considered invalid by the safety pilot due to pilot technique. However, as noted on Figure 23c, the pilot comments were consistent with a low pitch attitude bandwidth, which is certainly a feature of that configuration. A review of the same pilot's comments for 8-3-5-1 (HQR=3) reveals impending problems with control of attitude and flight path, albeit still good enough to be Level 1. These results are interpreted to mean that attitude bandwidth approaches a limiting value in the region of 1.2

to 1.3 rad/sec for ACAH response-types (see Figure 23c).

- Configuration 6-1-1-1 is rated as a 3 but falls in a region of Level 2 ratings in Figure 21 ($\omega_{BW_\theta} \doteq 1.9$ rad/sec, $\omega_{BW_\gamma} \doteq 0.6$ rad/sec). However, it has a step-like short-term α response to a step δ_{es} input and would pass a criterion based on that rather than flight path bandwidth. In addition, the Bode asymptotes are K/s from 0.38 to 2.27 rad/sec, i.e., well beyond the region of piloted crossover.

The fact that $(1/T_{\theta_2})_{eff}$ does not correlate the pilot rating data for the precision landing tests in Reference 2 and Appendix A does not eliminate it as an important flying qualities parameter. Clearly, it is important when the pilot adopts a series strategy such as for ILS or visual glide slope tracking. In this case, the bandwidth of the inner attitude loop is much greater than that for the outer path loop (1.5 to 2 vs. approximately 0.3 rad/sec). Such a wide separation in frequency allows the pilot to spend most of his time on attitude with occasional corrections in flight path resulting in an effectively simultaneous closure. That is, the dynamics of the flight path response are effectively in the presence of a closed attitude loop. If the bandwidth of the flight path loop approaches that of the attitude loop, the pilot will have a difficult time simultaneously closing both loops and will probably pay attention to attitude only as required for stabilization. The generic effects of flight path control with and without an inner attitude loop closure are shown in Figure 24. The shape of the γ/δ_{es} frequency response is always K/s in the presence of a continuous attitude loop closure, because it is equivalent to an ACAH response-type where the pilot supplies the attitude feedback. Clearly, the pilot will close a continuous attitude loop whenever possible, but in some cases, this may be beyond his capability. Hence it is important to require Level 1 values of ω_{BW_γ} <u>and</u> $(1/T_{\theta_2})_{eff}$.

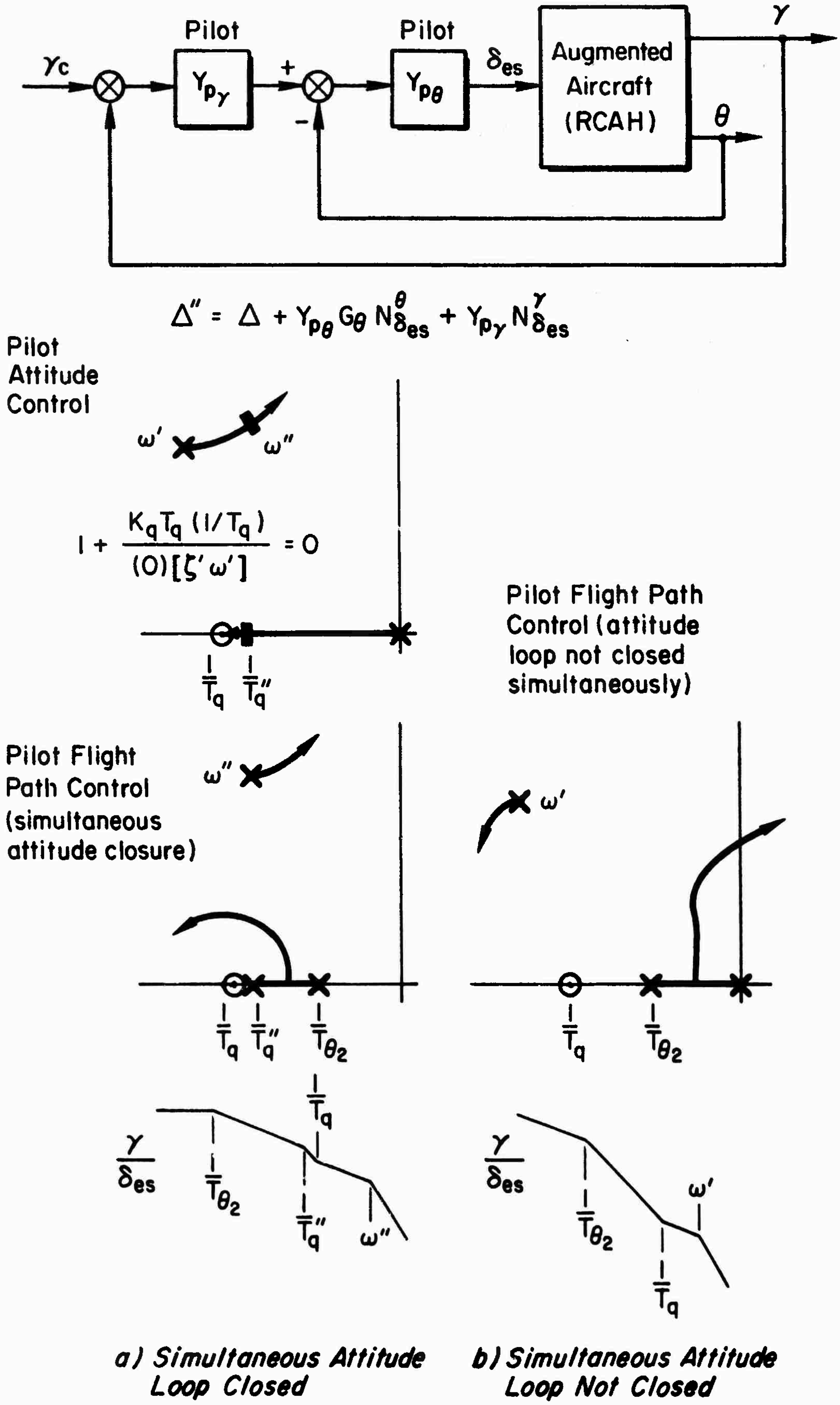


Figure 24. Effect of Simultaneous Attitude Loop Closure on Flight Path Loop

D. FORMULATION OF CRITERIA

Based on the data correlations discussed above, the flight path control criteria for precision landings should have the following essential features.

1. The γ/δ_{es} response should be K/s in the region of piloted crossover for flare (on the order of 0.5 to 2 rad/sec), and should have adequate bandwidth.

2. There must be adequate energy available to modify the flight path with pitch attitude (this has not been discussed here, but it is an obvious requirement, as described in Reference 10).

3. Ideally, the attitude response-type should be attitude command/attitude hold.

4. The lag between attitude and flight path $(1/T_{\theta_2})_{eff}$ must not be excessively large.

The first of these requirements is generally satisfied if the bandwidth of the attitude-to-longitudinal controller is at least 2.5 rad/sec and the short-term (five seconds) angle-of-attack response to a step longitudinal controller input is a step (see Figure 23). This form of the criterion results in very good correlation with the Reference 2 and Appendix A pilot rating data as illustrated in Figures 23b and 23c. Based on comparisons with the generic variations in the angle-of-attack response with the shape of the γ/δ_{es} frequency response (see, for example, Figure 18), it appears that the step response in α should reach zero slope ($\dot{\alpha} = 0$) in less than five seconds. The criterion is worded to reflect this by requiring zero slope in less than five seconds in addition to exhibiting the general characteristics of a step response in that time period. Possible deficiencies in this criterion are that borderline cases (nearly zero slope) could be acceptable but fail the criterion (such as the case with $1/T_q = 1.5$ and $1/T_{\theta_2} = 1$ in Figure 18b), or an unusual γ numerator zero could result in a lack of correspondence between the step α time response and the -20 dB/decade slope in the γ/δ_{es} frequency response. Both of these deficiencies would be circumvented by specifying a minimum level of ω_{BW_γ}. For this reason ω_{BW_γ} is specified as an alternate criterion. It is not specified as the primary criterion because it tends to be overly conservative, and because it is significantly more difficult to measure than the angle-of-attack time response to a step longitudinal controller input.

A Level 1 limit of $\omega_{BW_\gamma} > 0.8$ rad/sec was established (for the secondary criterion) based on the data in Figures 21 and 22. While it was tempting to specify a lower value of ω_{BW_γ} for attitude command/attitude hold (ACAH) than for rate command/attitude hold (RCAH), such a relaxation would only be supported by two data points (Configurations 6-1-1-1 and 8-3-5-1). Specifying a step α response (as the primary criterion) circumvents this issue to some extent, although it shows up indirectly in the specification of the minimum pitch attitude bandwidth. That is, the data correlations in Figure 23 would support a lower ω_{BW_θ} for ACAH than for RCAH (and ω_{BW_γ} is a function of ω_{BW_θ} as long as the α response is a step).

The effect of an unusual γ numerator is discussed in the following subsection.

The change in pitch attitude required to accomplish the flare (or flight path corrections for no-flare landings) should not be excessive, and minimum acceptable values may be derived from the Reference 10 data repeated in Figure 25. If no-flare landings are specified, acceptable pilot ratings would be expected for somewhat reduced values of $\Delta\gamma_{max}/\Delta\theta_{ss}$. However, such a relaxation is not recommended since substantiating data is not available, and moderate changes in flight-path angle may be required for recovery from off-nominal conditions and/or regulation against a windshear.

The data from Reference 2 and Appendix A show a clear pilot preference for attitude command/attitude hold. However, Level 1 ratings are possible with rate command/attitude hold, so such systems must be allowed.

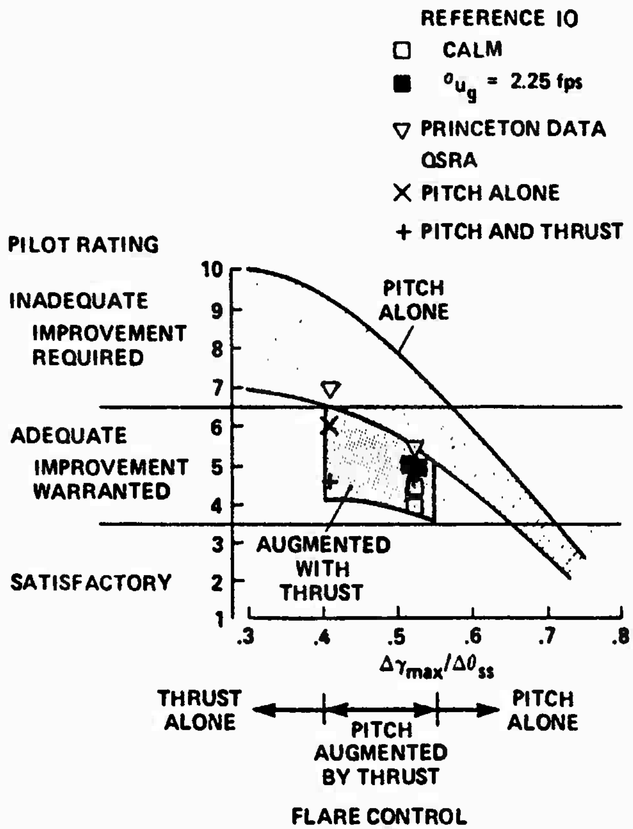


Figure 25. Energy Required for Flare with Attitude (from Reference 10)

E. WHY NOT LOWER ORDER EQUIVALENT SYSTEMS?

The first criterion for attitude control listed in the proposed MIL Handbook (Reference 1) is based on a Lower Order Equivalent Systems (LOES) criterion. The primary advantage of this criterion is that it allows the use of the existing "control anticipation parameter" (CAP) boundaries from MIL-F-8785B or C. These boundaries are based on variations in classical airplane short period frequency and damping from variable stability NT-33 flight tests. The lower order equivalent form is the short period approximation for classical airplanes (see Reference 18), with the addition of a pure time delay (τ_e) to account for high frequency lags. As discussed in Reference 1, the equivalent values of short period frequency (ω_e), damping (ζ_e), τ_e and $1/T_{\theta_2}$ are based on simultaneously matching pitch rate and flight path to the following lower order forms.

$$\frac{q}{\delta_{es}} = \frac{(s + 1/T_{\theta_2})e^{-\tau_e s}}{s^2 + 2\zeta_e \omega_e s + \omega_e^2}$$

and

$$\frac{n_z'}{\delta_{es}} = \frac{Kn_z e^{-\tau_{e_{n_z}} s}}{s^2 + 2\zeta_e \omega_e s + \omega_e^2}$$

Because of the simultaneous matching, the value of $1/T_{\theta_2}$ is preserved as the flight path lag, and is effectively fixed. This is, of course, as it should be since the CAP criterion is based on attitude (ω_e and ζ_e) and path ($1/T_{\theta_2} \doteq \frac{U_o}{g}\frac{n}{\alpha}$), therefore, freeing $1/T_{\theta_2}$ without consideration for the path response is not correct.

The problem arises when the higher order system is not augmented to look like a classical airplane. Examples of this are given below.

- Attitude command/attitude hold does not look at all like the classical airplane short-period approximation, and therefore does not apply to the CAP boundaries.

- Additional modes in the region of fitting result in misleading and erroneous equivalent values. This is discussed in detail in Reference 1, where it is shown that such additional modes resulted in negative values of τ_e, and indicated (erroneously) a need to increase the minimum damping boundary from .35 to .5. This is a result of attempting to fit a response which is fundamentally higher order with a lower order function. The mathematics, knowing nothing about handling qualities, make adjustments to ω_e, ζ_e, and τ_e which are not physically meaningful, even though the fit between the lower and higher order systems may be excellent. Results such as a negative τ_e are obvious, but other anomalous variations in ω_e and ζ_e are usually more subtle, and could easily result in improper interpretations (such as increasing the lower damping boundary in Reference 1, or see Reference 37).

- The use of LOES for RCAH is inappropriate if $1/T_{\theta_2}$ is not approximately equal to $1/T_q$ (see Figure 15) since the numerator of q/δ_{es} is not the same as the flight path lag, $1/T_{\theta_2}$. The fitting routine will adjust ω_e, ζ_e and τ_e to account for this discrepency, yielding a result which is not in accordance with the basic physics of the problem, i.e., it is not correct to vary ζ_e and ω_e to account for a separation between $1/T_{\theta_2}$ and $1/T_q$. Actually, we have shown that a wide separation in $1/T_{\theta_2}$ and $1/T_q$ results in flight path control problems (at lease in the flare) which would not be predicted by the CAP boundaries.

In summary, the Lower Order Equivalent Systems criterion, as it now exists, only applies to a special class of augmentation where the higher order airplane has classical response characteristics, i.e., as illustrated in Figure 17a. The use of LOES and the CAP boundaries for any other type of augmentation is risky, as illustrated by the above examples. Since STOL aircraft are rarely augmented to look like a classical airplane (usually have pure rate, RCAH, or ACAH augmentation), the LOES/ CAP criterion, in its present classical airplane form, is not appropriate. Some consideration was given to developing LOES criteria for RCAH and ACAH augmentation, but there was insufficient data to develop criterion boundaries (separate boundaries would be required for rate and ACAH response types). Furthermore, the bandwidth criterion does not depend on the form of the response, and is more directly suited as a criterion for highly augmented aircraft.

F. CONSIDERATION OF RECENT DATA FROM TIFS

A follow-on program to the Reference 2 in-flight simulation has recently been completed. Very preliminary data were provided to STI. A complete analysis of this data is beyond the scope of the present study. However, a preliminary examination of the data indicates serious discrepancies with the criteria developed herein. Of particular concern is the fact that several configurations with a monotonically increasing short-term α response (to a step δ_{es} input) resulted in Level 1 ratings, while other configurations with a short-term step α response were rated Level 2. A repeat configuration (Configuration 1-2-2 in Reference 2, and Configuration 17 in the recent study) was given Cooper-Harper pilot ratings of 8 and 5.5 during the Reference 2 experiment and 2,3,2,4,2 in the recent experiment (from five different pilots). The same pilot who rated this configuration 7 and 8 on repeat trials the first time, gave it a 2 on the most recent evaluations. A very conventional configuration (ω_{sp} = 2 rad/sec, ζ_{sp} = 0.7, $1/T_{\theta_2}$ = 0.91 rad/sec) was rated 6,6,3 in the recent tests, whereas a similarly conventional configuration (7-1-4) was rated 3,2.5 during the first series of tests. One area of consistency between the two flight test experiments was the fact that ACAH configurations were rated Level 1, further verifying the robustness of this response-type for precision landings.

A very brief analysis was conducted in an attempt to identify some fundamental difference between the configurations in the two experiments, recognizing that the tasks and experimental scenarios were identical. It was found that the γ numerator zeros were configured in an unusual way. That is, the flight-path-angle-to-elevator numerator usually consists of a low-frequency zero, which is in the right-half-plane if the aircraft is on the backside of the power-required curve, and two approximately symmetrical high-frequency zeros on the real axis for aft tails, or an imaginary pair for a forward tail (or an equivalent DLC). The approximate factors for $N^{\gamma}_{\delta_e}$ for a conventional aft-tail airplane, are as follows (from Reference 19).

$$N^{\gamma}_{\delta_e} = \frac{Z_{\delta_e}}{U_o}\left(s + \frac{1}{T_{\gamma_1}}\right)\left(s + \frac{1}{T_{\gamma_2}}\right)\left(s + \frac{1}{T_{\gamma_3}}\right)$$

$$\frac{1}{T_{\gamma_1}} \doteq -X_u + (X_\alpha - g)\frac{Z_u}{Z_\alpha}$$

$$\frac{1}{T_{\gamma_2}} \doteq -\frac{1}{T_{\gamma_3}} \doteq \left(M_\alpha - \frac{M_{\delta_e}}{Z_{\delta_e}} Z_\alpha\right)^{1/2}$$

Note that $1/T_{\gamma_2}$ and $1/T_{\gamma_3}$ depend on $M_{\delta_e}/Z_{\delta_e}$ and can take on relatively small values (near the region of crossover) only for a large elevator with a relatively small tail arm. The γ/δ_e numerators for the configurations in Reference 2 are relatively conventional, whereas they are somewhat unconventional in the configurations developed for the recent program. Some typical values are:*

- Reference 2

$$N_{\delta_e}^{\gamma} = -12.5(s + 0.015)(s + 2.4)(s - 1.9) \text{ Configuration 1-1-1}$$

$$-13.7(s + 0.081)(s + 2.57)(s - 3.11) \text{ Configuration 4-2-2}$$

$$-10.4(s + 0.004)(s + 3.08)(s - 2.54) \text{ Configuration 7-1-4}$$

- Recent flight tests

$$N_{\delta_e}^{\gamma} = A_\gamma(s)(s + 0.95)(s - 3.86) \text{ Configuration 2}$$

$$= A_\gamma(s)(s + 1.42)(s - 4.45) \text{ Configuration 5}$$

The fact that $1/T_{\gamma_2}$ is relatively small and not approximately equal to $-1/T_{\gamma_3}$ for Configurations 2 and 5 in the recent study invalidates the relationship established between a short-term step α time response and a -20 dB/decade slope in the γ/δ_{es} frequency response. This is demonstrated in Figure 26 for Configuration 2 where the short-term α time response is a ramp ($t < 5$ sec) and the γ/δ_{es} frequency response is

---

*It should be noted that these values were calculated from preliminary unpublished data which may have been revised.

$$\frac{\theta}{\delta_{es}} = \frac{M_{\delta_{es}}}{(0)(8)} e^{-.175s} \qquad 1/T_{\theta_2} = 0.50 \text{ 1/sec} \qquad \omega_{BW_\theta} = 2.69 \text{ rad/sec}$$

$$\text{HQR} = 3/3/6 \qquad \omega_{BW_\gamma} = 1.04 \text{ rad/sec}$$

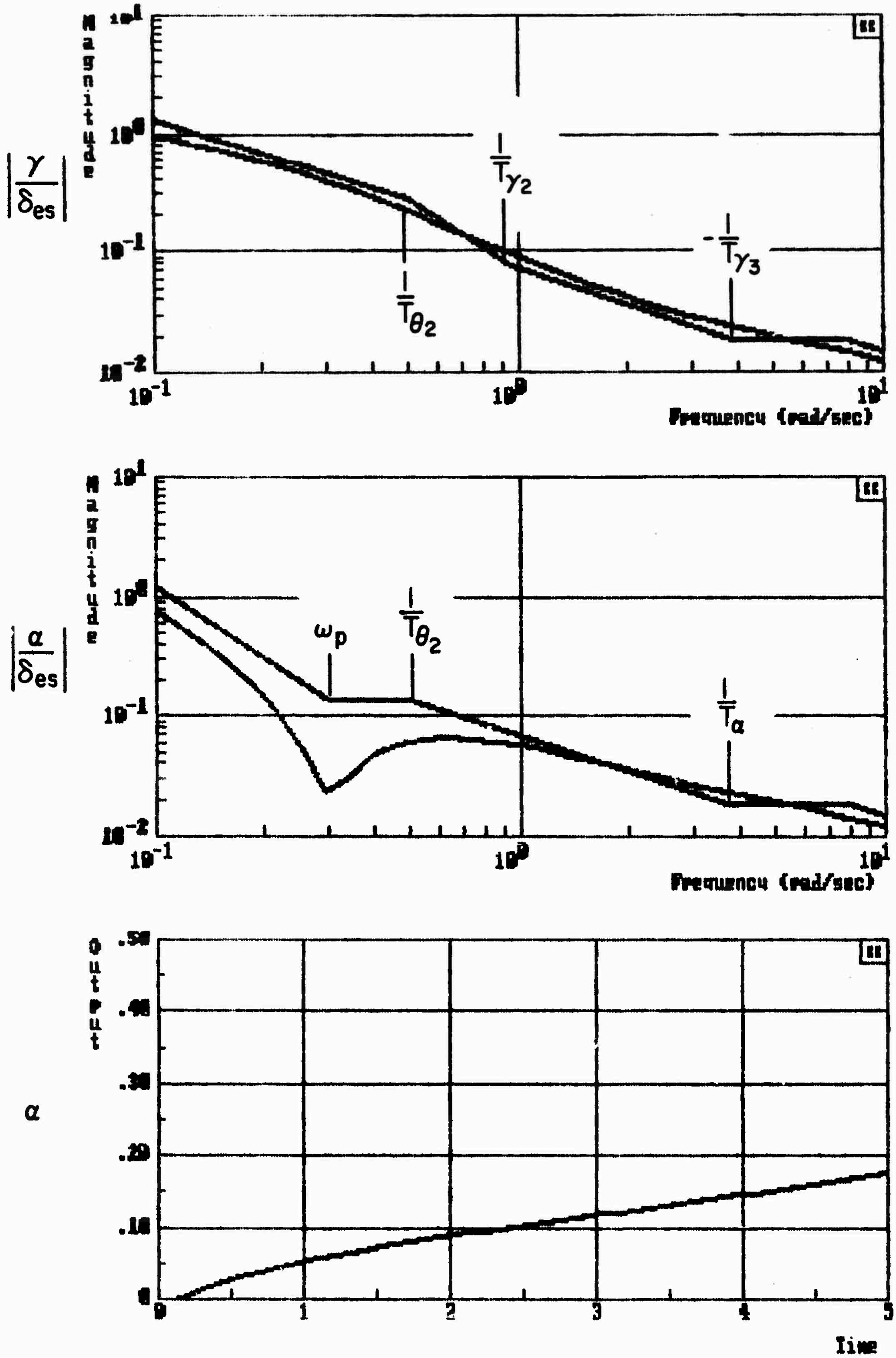


Figure 26. Characteristics of Configuration 2 from Recent TIFS Flight Tests

K/s.* Two pilots rated Configuration 2 Level 1 (Cooper-Harper ratings of 3 and 3), which is consistent with the basic crossover model theory (Reference 22) that the primary requirement is for a K/s response in γ/δ_{es}. However, this is confounded by a third pilot who rated this configuration a 6. This third pilot "had knowledge of the configuration being evaluated" and may have expected problems due to the ramp α characteristics of this configuration based on preflight discussions. Since we do not have access to the pilot commentary, it is not possible to take them into account.

It is not clear what details of the variable stability simulation resulted in such an unusual separation in frequency between $1/T_{\gamma_2}$ and $1/T_{\gamma_3}$, or if such a value is physically realizable. This is of interest, since such values of $1/T_{\gamma_2}$ do not allow the convenience of using the α time response as a measure of the shape of the γ/δ_{es} frequency response, i.e., the proposed primary criterion for path control is invalid. The most foolproof alternative is to require measurement of the γ/δ_{es} frequency response via in-flight frequency sweeps and subsequent data analysis using Fast Fourier Transforms. Such measurements could be used to simply obtain the flight-path bandwidth ω_{BW_γ}, and/or to supply the slope of $|\gamma/\delta_{es}|$ in the region of crossover.

Configuration 5 from the recent tests represents a conventional aircraft which would be expected to exhibit Level 1 handling qualities, and yet was rated 6 by two pilots and 3 by a third pilot. The response characteristics are conventional in every respect (see Figure 27 and compare to the generic conventional response in Figure 17a). The Reference 2 test results showed that such conventional aircraft response characteristics are desirable for the precision landing task (Configuration 7-1-4 in Figures 22 and 23).

From the above discussion, it can be seen that apparent discrepancies exist between the most recent data, the proposed criteria, the

---

*This is because $1/T_{\gamma_2}$ appears in the numerator $N^{\gamma}_{\delta_{es}}$ but not in the numerator $N^{\alpha}_{\delta_{es}}$.

$\omega_{sp} = 2$, $\zeta_{sp} = .7$, $\omega_p = .10$, $\zeta_p = .10$, HQR = 6/6/3

$1/T_{\theta_2} = .9$ 1/sec , $\omega_{BW_\theta} = 1.96$ rad/sec , $\omega_{BW_\gamma} = 1.25$ rad/sec

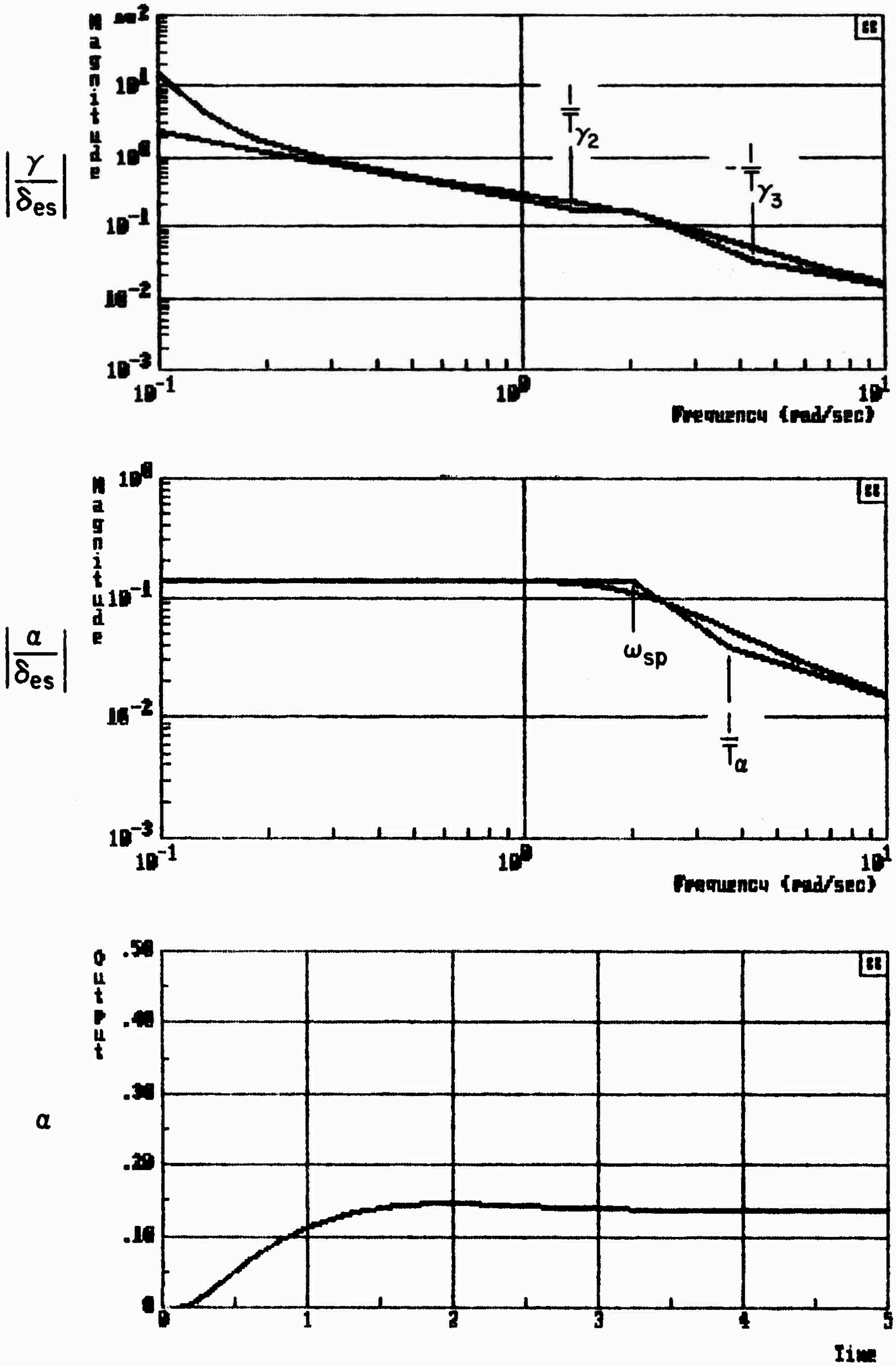


Figure 27. Characteristics of Configuration 5 from Recent TIFS Flight Tests

original tests from Reference 2, and the piloted moving-base simulation results in Appendix A. A brief review of the new data suggests that an unusual separation in frequency between $1/T_{\gamma_2}$ and $1/T_{\gamma_3}$ may explain some of these results. However, the wide variation in pilot ratings for the same configuration suggests some uncertainty in the results. Some of this may be explained once the evaluation pilot and safety pilot commentary are transcribed.

One may also conjecture as to the sufficiency of two landings as a basis for evaluating what could be subtle, yet important differences. Piloted evaluations of landings has always been difficult because of the variability of the initial condition at flare initiation, and the short exposure to the critical environment (about 10 seconds per landing). Unfortunately, the limited budget afforded handling qualities flight research rarely allows sufficient repeat runs to identify sometimes elusive deficiencies, a fact which may be responsible for the above discrepancies. Interestingly, experience has shown that the worst judge of the need for repeat runs is usually the evaluation pilot. Forced to accomplish three or more repeat runs, the evaluators will invariably resist, and also invariably, will identify important features on the repeat evaluations which were not identified during the first few runs. Given a limited budget, the experimenter is caught on the horns of a dilemma: running many repeat runs limits the size of the matrix, and many questions remain unresolved, while limiting the repeat runs results in questionable experimental validity. In the present case, most of the data is unavailable, and we are privy to only partial information. However, it does appear that discrepancies exist.

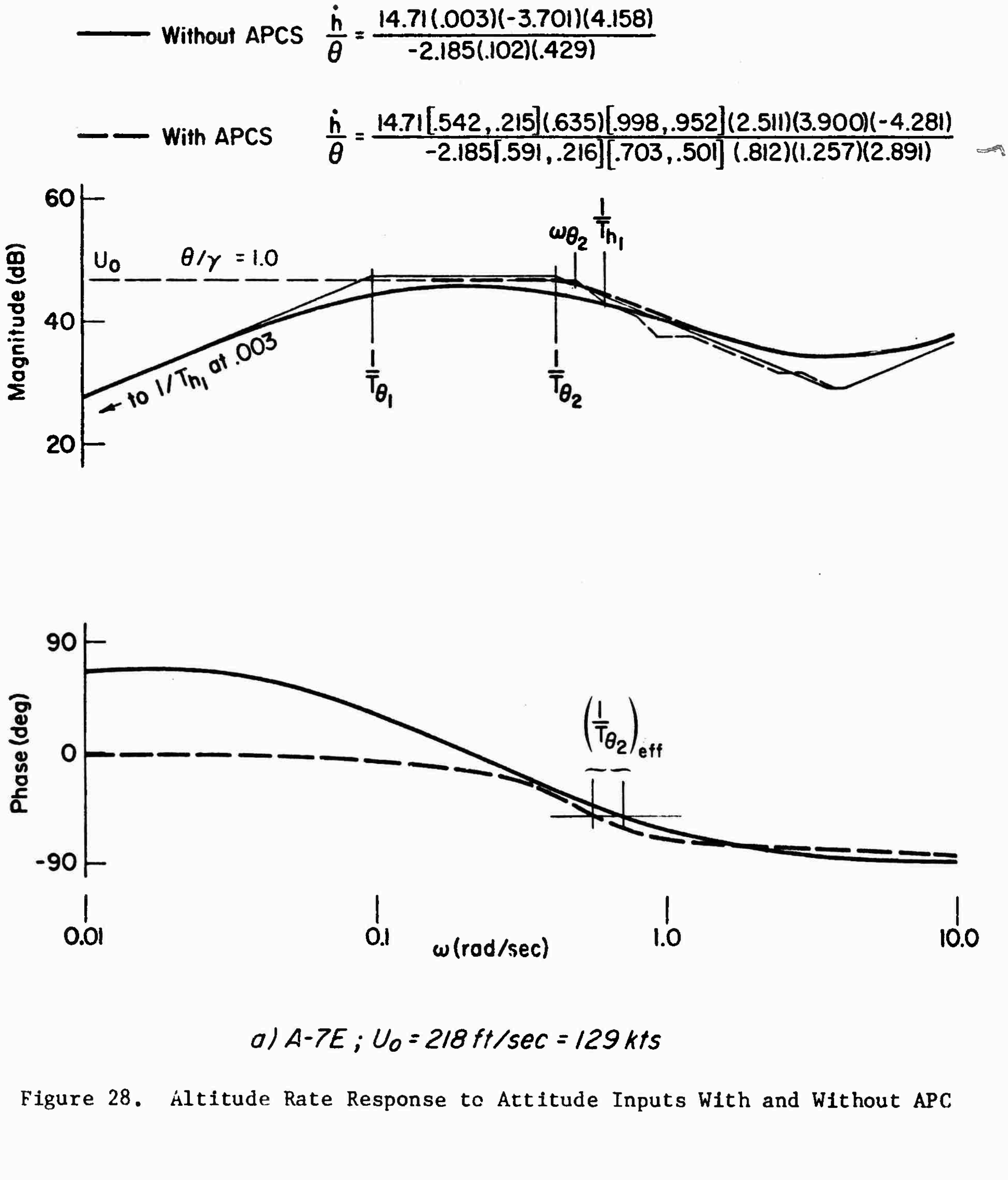
G. EFFECT OF AN AUTOTHROTTLE

Precision flight path control is greatly enhanced by the use of an autothrottle for aircraft where $(d\gamma/dV)_{\delta_T = \text{const}} > 0$ (backside). For example, autothrottles (Approach Power Compensators or APC) are commonly used on carrier-based aircraft, for example, see Reference 23. The primary advantage of an autothrottle is for mid-to-low-frequency airspeed control. That is, the pilot is relieved of the task of controlling airspeed (or angle-of-attack) with throttle during the approach. Attempts to improve the flight path response with an autothrottle result in excessive engine surging, or abrupt longitudinal accelerations if thrust is modulated via reversers. Hence, the autothrottle will have very little effect on the precision control of flight path for short final and landing. This is illustrated for two typical APCs in terms of γ/θ in Figure 28 (taken from Reference 23). Note that $(1/T_{\theta_2})_{eff}$ is unchanged in both cases.

Some deficiencies in the APCs used on current Navy aircraft are discussed in Reference 23 and are summarized below.

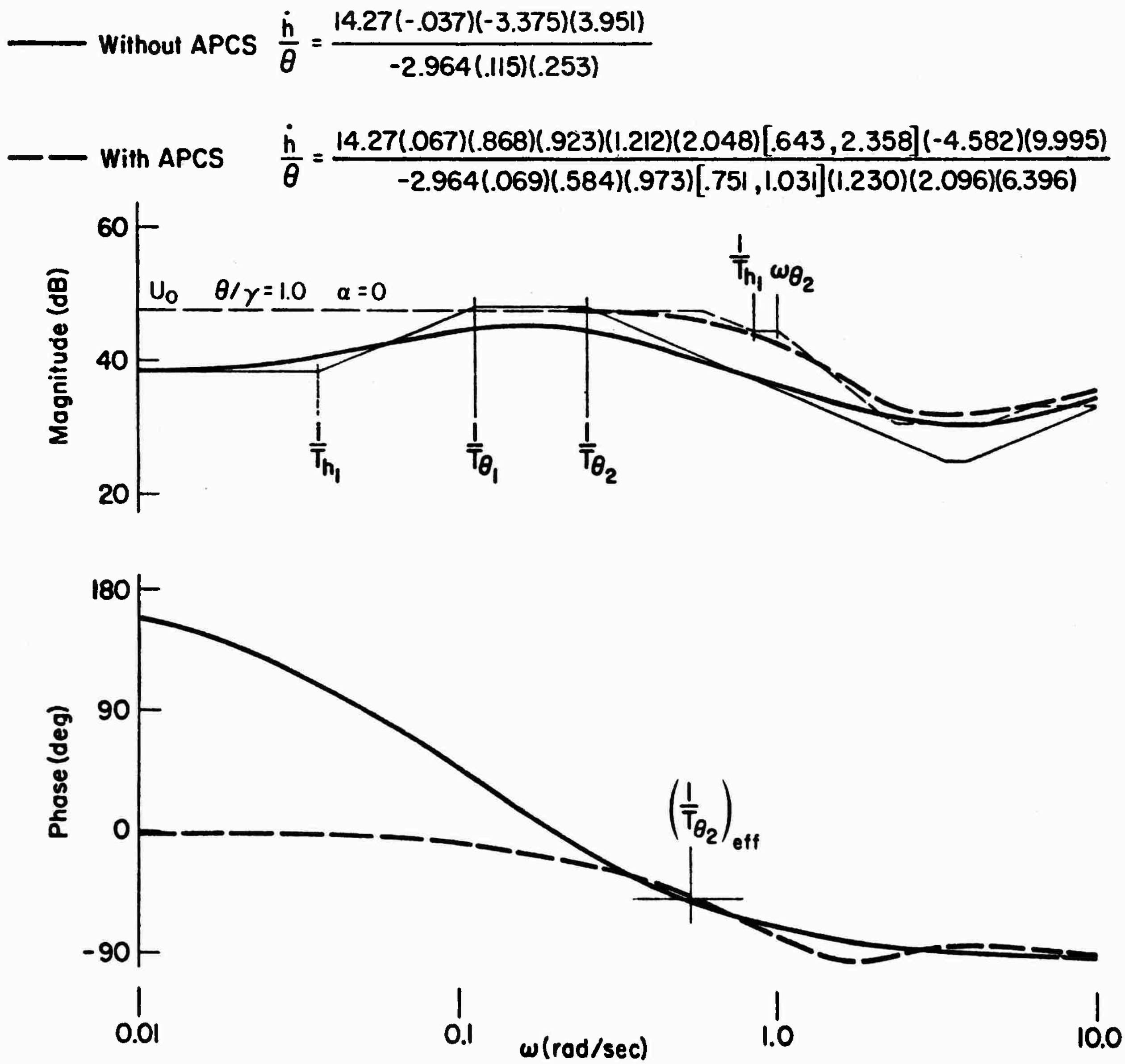
- excessive throttle motions
- excessive pitch attitude changes required to make glide slope corrections [low $(1/T_{\theta_2})_{eff}$]
- excessive control sensitivity
- excessive angle-of-attack and airspeed excursions
  - -- in windshears
  - -- during turn entry and exit
  - -- during glide slope intercept
- tendency for low frequency pilot-induced oscillations on glide path

It would require a substantial research effort to develop handling qualities criteria for autothrottle systems. Since no such efforts are currently planned, the development of satisfactory systems will have to be accomplished on a case-by-case basis. The criteria presented in Section III-A (frontside flight-path control) apply with or without an autothrottle, since they relate to short-term flight path control.



a) A-7E ; U_o = 218 ft/sec = 129 kts

Figure 28. Altitude Rate Response to Attitude Inputs With and Without APC



b) F-4J ; U_0 = 220.8 ft/sec = 131 kts

Figure 28. (Concluded)

SECTION V

DEVELOPMENT OF STOL SIMULATION TEST PLAN AND DISCUSSION OF PROPOSED CRITERION PARAMETERS

A. INTRODUCTION

A significant portion of this research has been devoted to identifying gaps in the data base that prevent the development of STOL handling qualities criteria. Configurations were formulated as elements of a comprehensive test matrix for piloted simulation (see Appendix B). This involved the determination of airplane characteristics that provided a systematic variation in proposed longitudional and lateral handling qualities criterion parameters. A computer program (Reference 24) was developed to facilitate this process by calculating a wide variety of proposed criteria, given the augmented airplane transfer functions. The program runs on a DEC PDP 11/34 minicomputer and has been supplied to FIGC as part of this contract. The resulting test matrix is given in Appendix B in terms of transfer functions. A portion of this matrix was accomplished on the AFWAL/FIGC LAMARS moving-base simulation with the results presented in Appendix A and discussed in Section IV.

In the remainder of this section, the interrelationships of the proposed criterion parameters with each other, and with some currently proposed boundaries, are discussed.

1. Available Data

A quite comprehensive review of STOL handling qualities data generated over the past twenty years is presented in Reference 3; more recent data is discussed in Sections II through IV of this report. For the most part, the references discussed in Reference 3 represent data for transport-class (Classes II and III), powered-lift aircraft. This is a result of an extensive series of studies performed or sponsored by the U.S. FAA, British Civil Aviation Authority, NASA, and other organizations, in the mid-1970s to develop airworthiness standards for civil

STOL aircraft. In addition, the U.S. Air Force's Advanced Medium STOL Transport (AMST) program in the same time period led to simulation and flight testing of the YC-14 and YC-15 prototypes (References 25 and 26), designed to comply with a flying qualities specification (Reference 16) that was based largely on MIL-F-8785C.

Only recently has there been a focus on nonpowered-lift, fighter-type (Class IV) STOL designs (e.g., References 17, 27, and 28). And with only a few exceptions, most notably References 29, 30, and 31, there has been almost no quantitative investigation of lateral-directional requirements for any STOL design.

In summary, we can isolate three major subjects for which there is a glaring lack of STOL handling qualities data: 1) fighter STOLs; 2) nonpowered-lift designs; and 3) lateral-directional characteristics. The first two subject areas are typically closely related, since most proposed STOL fighters will employ a minimum of lift augmentation from thrust.

2. Focus of the Study

The analytical study described in this section was conducted to determine the interrelationship between the various handling qualities parameters proposed in this report and elsewhere. By doing so, some insights were made into many of the unique characteristics of the STOL handling qualities criteria. The remainder of this section will refer to the generic configurations documented in Appendix B, and especially the tables of handling qualities parameters, Tables B-1 and B-2.

B. LONGITUDINAL CRITERIA

1. Overview of Configurations

A total of forty-seven different longitudinal configurations were developed (Appendix B). The primary response variables were: response-type (ACAH vs. RCAH); attitude-to-flight-path lag, defined here in terms of the parameter $(1/T_{\theta_2})_{eff}$; pitch attitude and flight path bandwidth, ω_{BW_θ} and ω_{BW_γ}; time delay, represented by pure incremental delay;

long-term flight path stability, $d\gamma/dV$ or t_{rev}; and, for the RCAH response-types, pitch rate overshoot. Each of these response variables is directly related to one or more of the longitudinal STOL criteria proposed in this report. Each of the variables is discussed in more detail in the following subsections, focusing on insights gained from systematic changes in the variables.

2. Pitch Attitude Bandwidth and Time Delay

Pitch attitude bandwidth, ω_{BW_θ}, was varied through changes in control system gains. While this is not the only way to vary bandwidth (for example, the same variations could be obtained by modifying the basic aerodynamic derivatives), it is the most systematic, and most physically realistic. Four values of pitch attitude bandwidth were chosen for the ACAH systems (1.5, 3, 6, and 10 rad/sec) and for the RCAH systems (2, 4, 5, and 8 rad/sec). In addition, pure incremental time delay, $\Delta\tau$, was added in the forward loop for selected cases (an initial time delay of 12.5 msec was assumed to represent delay due to computation). The primary time delay variations were made for the ACAH response-types.

Figure 29 shows the sixteen ACAH cases developed for variations in bandwidth and time delay. Two observations can be made from this figure: addition of a moderate amount of time delay (0.1 sec) results in a 10-20 percent reduction in bandwidth, while further increases in delay, up to 0.2 sec, do not significantly reduce bandwidth further; the effect of incremental delay on the phase delay parameter τ_{p_θ} is greater for high-bandwidth systems than for low-bandwidth ones. Thus, the higher the initial bandwidth the more effect time delay will have on the system.

3. Flight Path Lag and Time Delay

Variations in flight path lag were accomplished by modifying the basic stability derivatives, primarily heave damping, Z_w. The flight path variations in Appendix B are separated based on values of the flight path/pitch attitude lag, $(1/T_{\theta_2})_{eff}$, defined in Section III. The

Note: ω_{BW_θ} and τ_{p_θ} are defined in Fig. 2

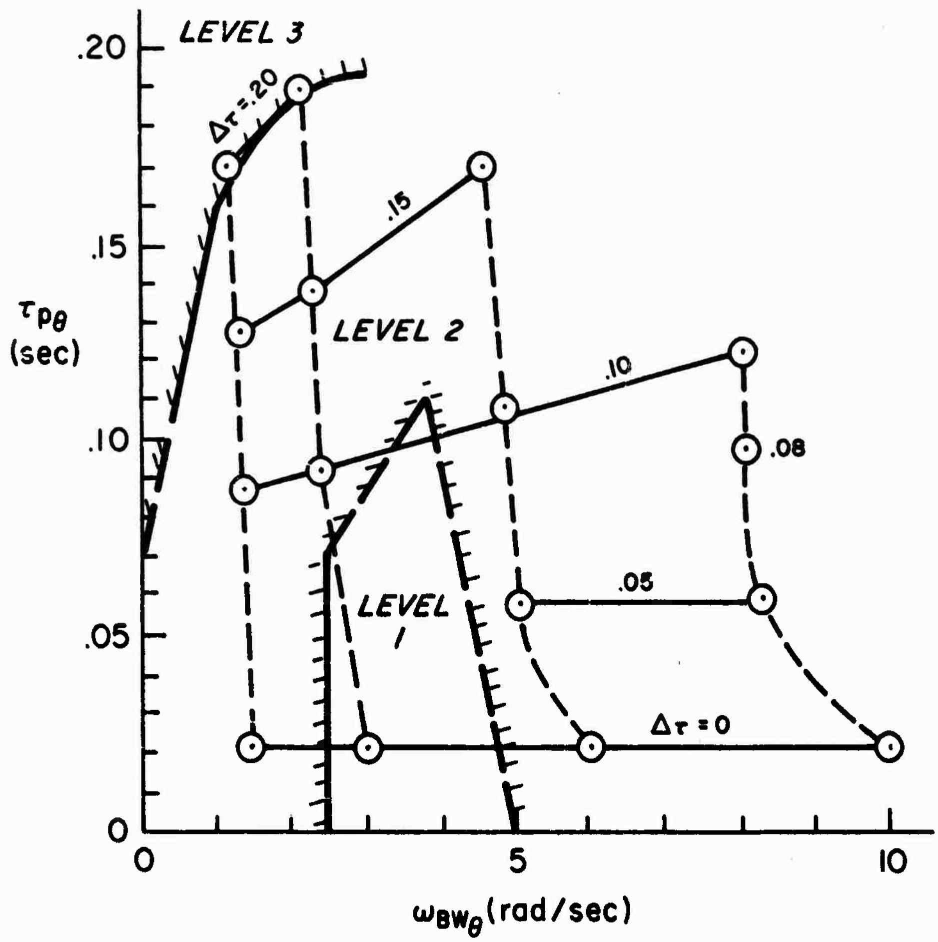


Figure 29. Effect of Incremental Time Delay on ω_{BW_θ} and τ_{p_θ} for ACAH Systems (Appendix B)

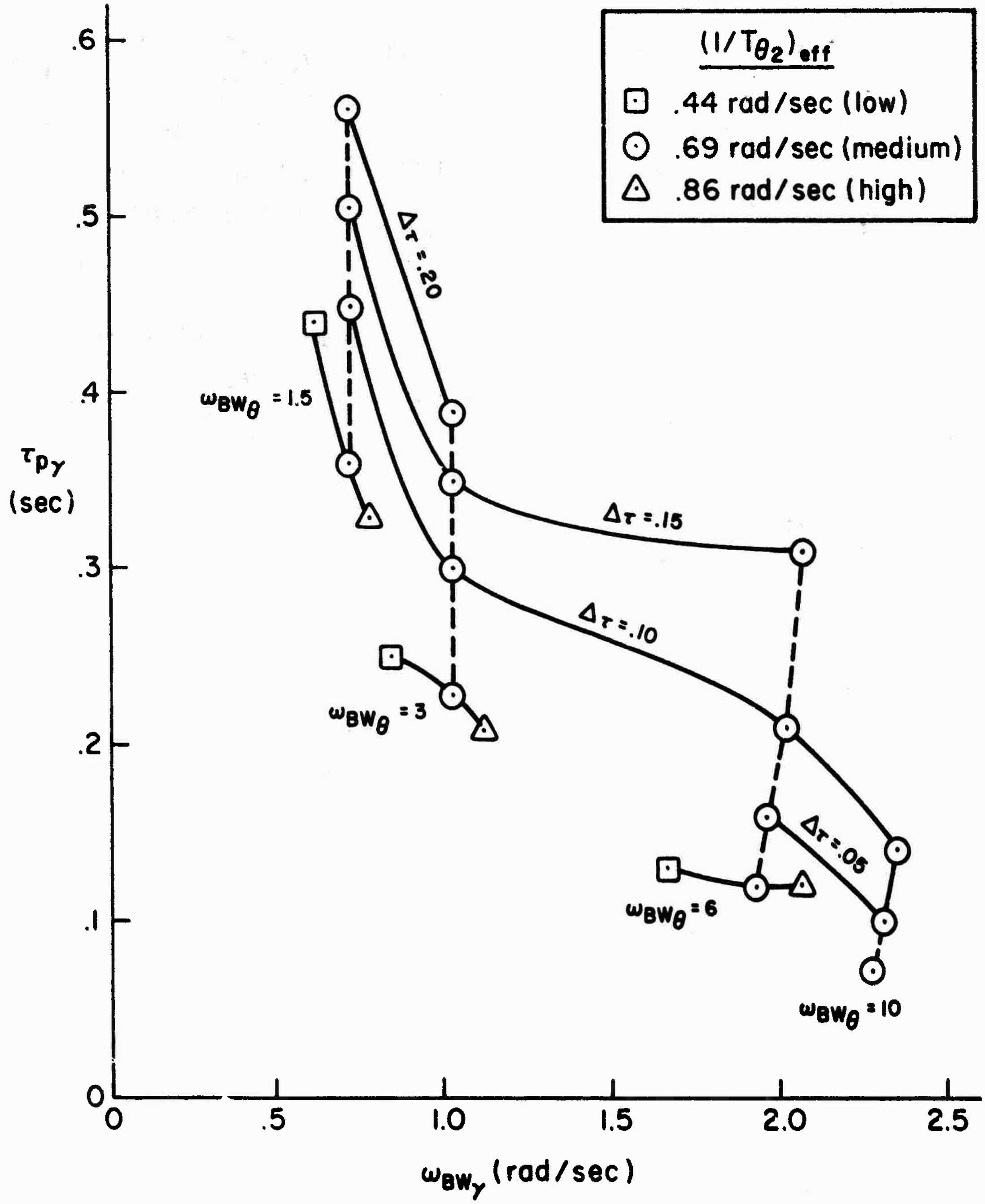
baseline aircraft has $(1/T_{\theta_2})_{eff} = 0.69$ rad/sec; additional values of 0.44 and 0.86 rad/sec were chosen, the former near the Level 1 limit of 0.38 rad/sec in Section III and the latter representing a possible optimum value.

Figure 30 summarizes the flight path bandwidth, ω_{BW_γ}, and phase delay, τ_{p_γ} for the ACAH and RCAH systems of Appendix B. The effects of ω_{BW_θ}, time delay, $(1/T_{\theta_2})_{eff}$, and -- for the RCAH cases, Figure 30b -- pitch rate overshoot, are shown.

For the ACAH response-types (Figure 30a), pitch attitude bandwidth has a considerable effect on both ω_{BW_γ} and τ_{p_γ}: as pitch bandwidth is increased, flight path bandwidth increases and delay decreases. Adding incremental time delay results in a significant increase in flight path phase delay, with no decrease in bandwidth -- in fact, there is a slight increase in bandwidth with time delay. Overall, path/attitude lag, $(1/T_{\theta_2})_{eff}$, has a relatively small influence on ω_{BW_γ} compared to either pitch attitude bandwidth or time delay.

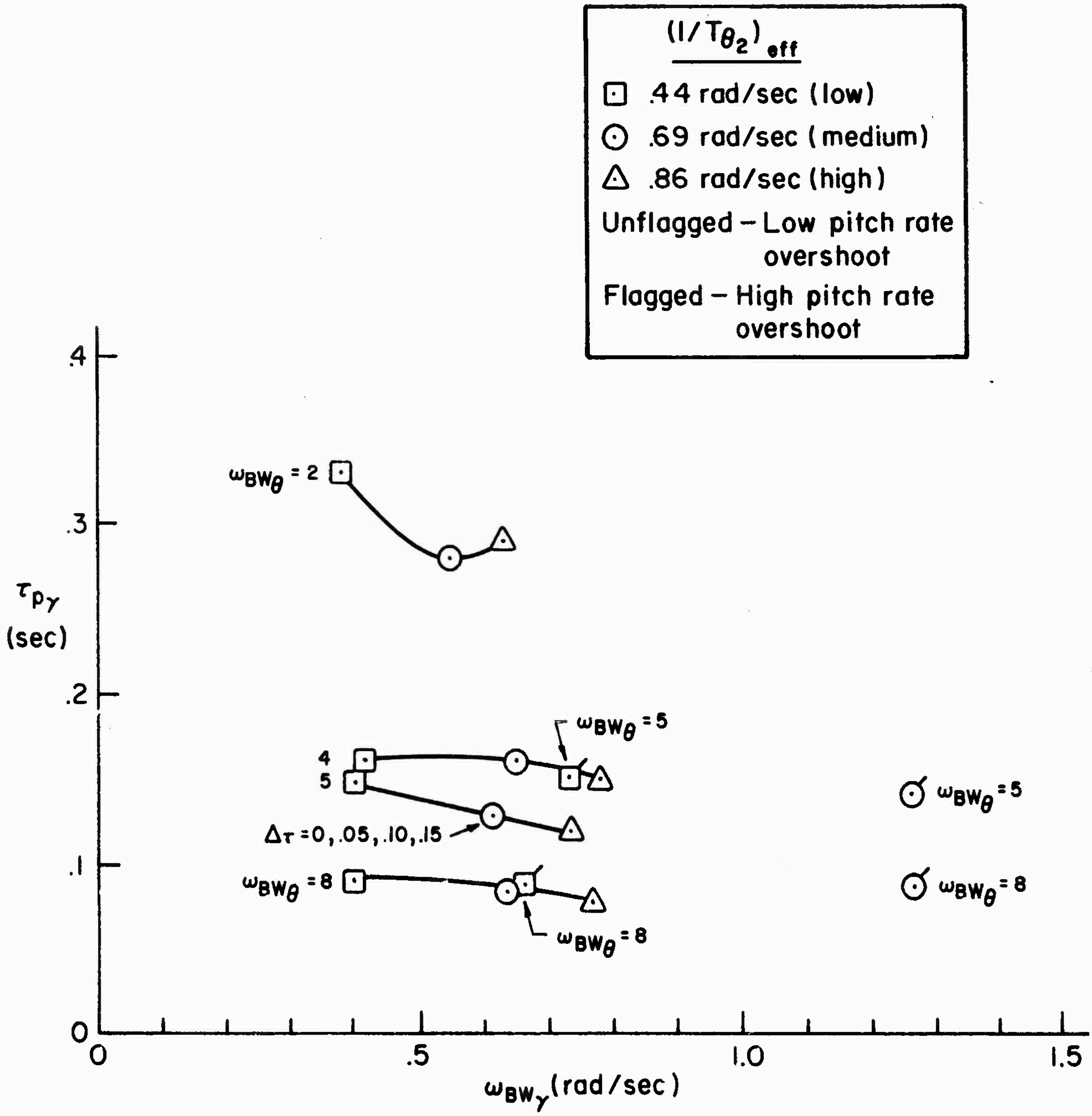
The story is quite different for RCAH response-types, however (Figure 30b): increasing pitch attitude bandwidth from 2 to 8 rad/sec reduces τ_{p_γ} but has almost no effect on ω_{BW_γ}. (Note the greatly expanded scale on ω_{BW_γ} in Figure 30b.) There is an almost one-to-one relationship between flight path bandwidth and path/attitude lag; i.e., doubling $(1/T_{\theta_2})_{eff}$ from 0.44 to 0.86 rad/sec results in an approximate doubling of ω_{BW_γ}. By far the most significant effect on flight path bandwidth is pitch rate overshoot: the high-overshoot cases (flagged symbols in Figure 30b) have path bandwidths about twice as high as the corresponding [in terms of ω_{BW_θ} and $(1/T_{\theta_2})_{eff}$] cases.

These trends may be explained in terms of the generic characteristics introduced in Section IV. Specifically, the flight path bandwidth, ω_{BW_γ}, is not a strong function of attitude bandwidth, ω_{BW_θ}, because $1/T_{\theta_2} << 1/T_q$ (see Figure 17b) for essentially all of the RCAH cases. (The higher values of ω_{BW_θ} are obtained by increasing $1/T_q$, Appendix B.) The pitch rate overshoot cases were obtained by decreasing $1/T_q$ so that $1/T_q \doteq 1/T_{\theta_2}$, resulting in a much higher value of ω_{BW_γ}.



a) ACAH Response-Types

Figure 30. Flight Path Bandwidth Variations (Appendix B)



b) RCAH Response-Types

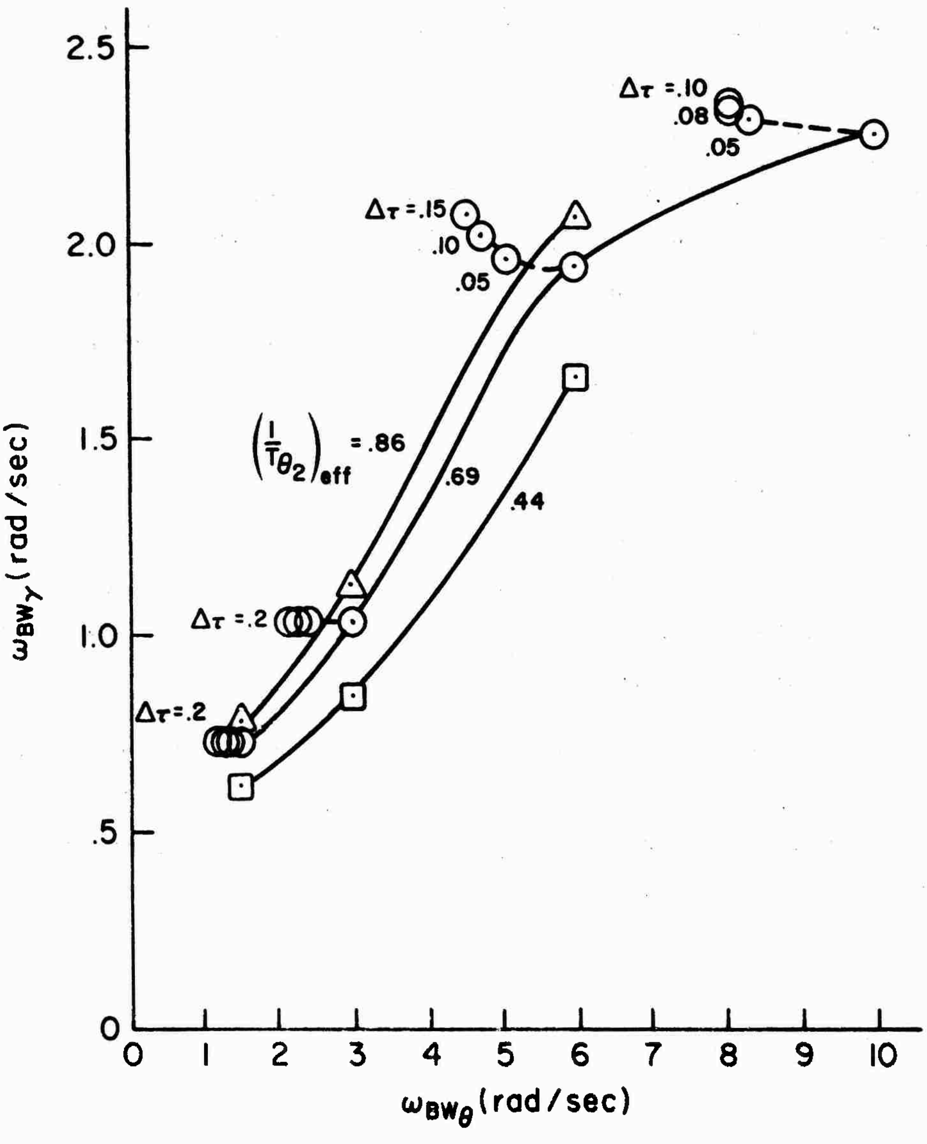
Figure 30. (Concluded)

Interestingly, time delay has no effect on flight path bandwidth, at least for the single instance where incremental time delays were added (indicated on Figure 30b). This is due to the fact that there is very little phase effect due to τ ($\Delta\phi = \tau\omega$) at the lower frequencies associated with flight path bandwidth.

The relationship between ω_{BW_θ} and ω_{BW_γ} is more clearly illustrated in Figure 31. When ω_{BW_θ} is crossplotted against ω_{BW_γ} for the ACAH response-types, Figure 31a, the correlation is approximately a straight line, with only a minor effect of $(1/T_{\theta_2})_{eff}$ and a small effect of time delay. This is not surprising, of course, since the example frequency responses presented in Section IV illustrated that for ACAH response-types both the flight path and pitch attitude responses to longitudinal controller are dominated by the closed-loop second-order response mode (Figures 15 and 16). Thus, as long as there are no unusual additional response modes in the flight path response, it is sufficient to measure only pitch attitude bandwidth for ACAH response-types, since flight path bandwidth is directly related to pitch bandwidth.

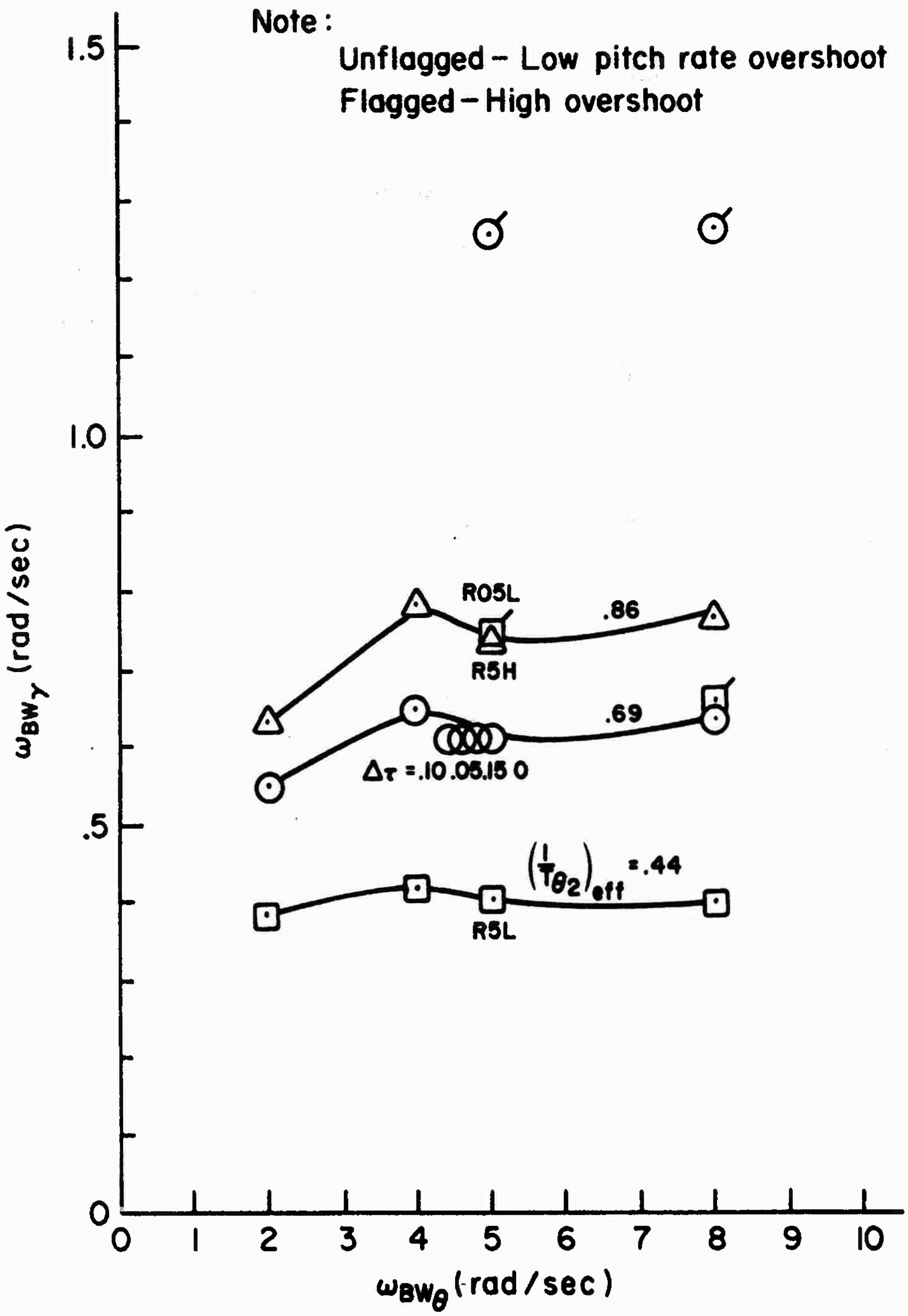
Figure 31b reveals just the opposite for RCAH response-types, confirming the observation from Figure 30b: ω_{BW_γ} is independent of ω_{BW_θ}. Since ω_{BW_γ} is a function of $(1/T_q - 1/T_{\theta_2})$, it is a strong function of pitch rate overshoot. Again, review of the generic frequency responses of Section IV suggests the reasons for these relationships: the frequency response of flight path to longitudinal controller is determined (in the region of piloted control) by both the closed-loop second-order mode, and the frequency separation between $1/T_q$ and $1/T_{\theta_2}$. This is clearly illustrated by Figure 32, where the ratio T_{θ_2}/T_q [representing $(1/T_q)/(1/T_{\theta_2})$] is plotted (as the logarithm of the ratio for convenience) against ω_{BW_γ}. Since $1/T_q$ is greater than $1/T_{\theta_2}$ for all the RCAH cases, $T_{\theta_2}/T_q > 1$ and $\log (T_{\theta_2}/T_q) > 0$.

The conclusions to be drawn are that 1) the most important factor in determining flight path bandwidth for ACAH response-types is pitch attitude bandwidth -- high values of the latter assure good values of the former; 2) pitch rate overshoot is critical to obtaining good flight path bandwidth for RCAH response-types (this is elaborated on below);



a) ACAH Response-Types

Figure 31. Pitch Attitude Bandwidth vs. Flight Path Bandwidth



b) RCAH Response-Types

Figure 31. (Concluded)

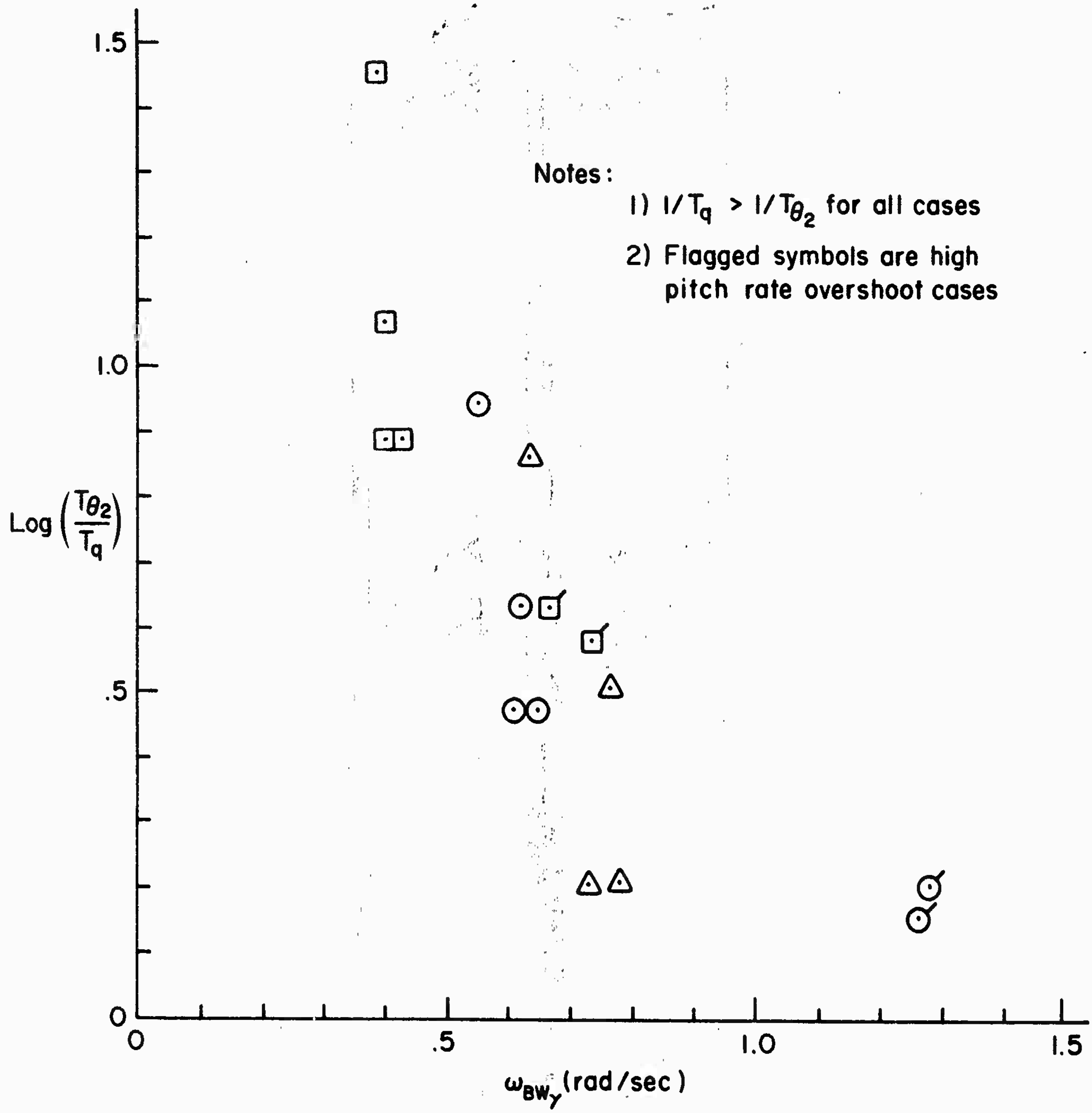


Figure 32. Effect of Frequency Separation Between $1/T_q$ and $1/T_{\theta_2}$ on Flight Path Bandwidth for RCAH Cases of Figure 31b

3) the actual value of $(1/T_{\theta_2})_{eff}$ for either response-type is a factor in flight path bandwidth, but of secondary importance in either case.

4. Importance of Pitch Rate Overshoot

This is a subject that has been the focus of controversy in the flying qualities community for a number of years: is pitch rate overshoot essential, and if so, why? Throughout this report, the importance of the pitch rate zero $1/T_q$ has been emphasized in determining both flight path bandwidth and the shape of the angle-of-attack time response. The previous subsection showed that both the frequency of the zero $1/T_{\theta_2}$ and the frequency separation between $1/T_{\theta_2}$ and $1/T_q$ determine flight path bandwidth for RCAH response-types. Therefore, there are two ways to provide flight path bandwidth for such response-types: make $(1/T_{\theta_2})_{eff}$ large, or intentionally provide overshoot.

The importance of pitch rate overshoot can be illustrated by looking at two RCAH cases from Appendix B. In Figure 31b there are two cases with almost identical pitch attitude bandwidth (5 rad/sec) and flight path bandwidth (0.74 rad/sec); in one instance (labeled R5H), the flight path bandwidth is provided by heave damping or $(1/T_{\theta_2})_{eff}$, while in the other case (R05L) it is provided by pitch rate overshoot. The latter case has a very low value of $(1/T_{\theta_2})_{eff}$, 0.44 rad/sec, identical to that of the low-overshoot Configuration R5L. Time histories of pitch attitude, flight path angle, and angle-of-attack to a pulse pitch attitude command input for these three cases are shown in Figure 33. Addition of pitch rate overshoot to the low-$(1/T_{\theta_2})_{eff}$ case -- i.e., going from R5L to R05L -- improves the quickness of the flight path response (note that the maximum flight path angle achieved is not increased, however; this is covered by the parameter $\Delta\gamma_{max}/\Delta\theta_{ss}$).

Figure 33 serves to confirm that the advantage of pitch rate overshoot is in the improved short-term flight path response, attained by effectively overdriving pitch attitude and angle-of-attack. This also indicates that overshoot is not essential, as long as $1/T_{\theta_2}$ for the basic aircraft is sufficiently large. Therefore, we would expect that (except for the possible effect of differences in $\Delta\gamma_{max}$)

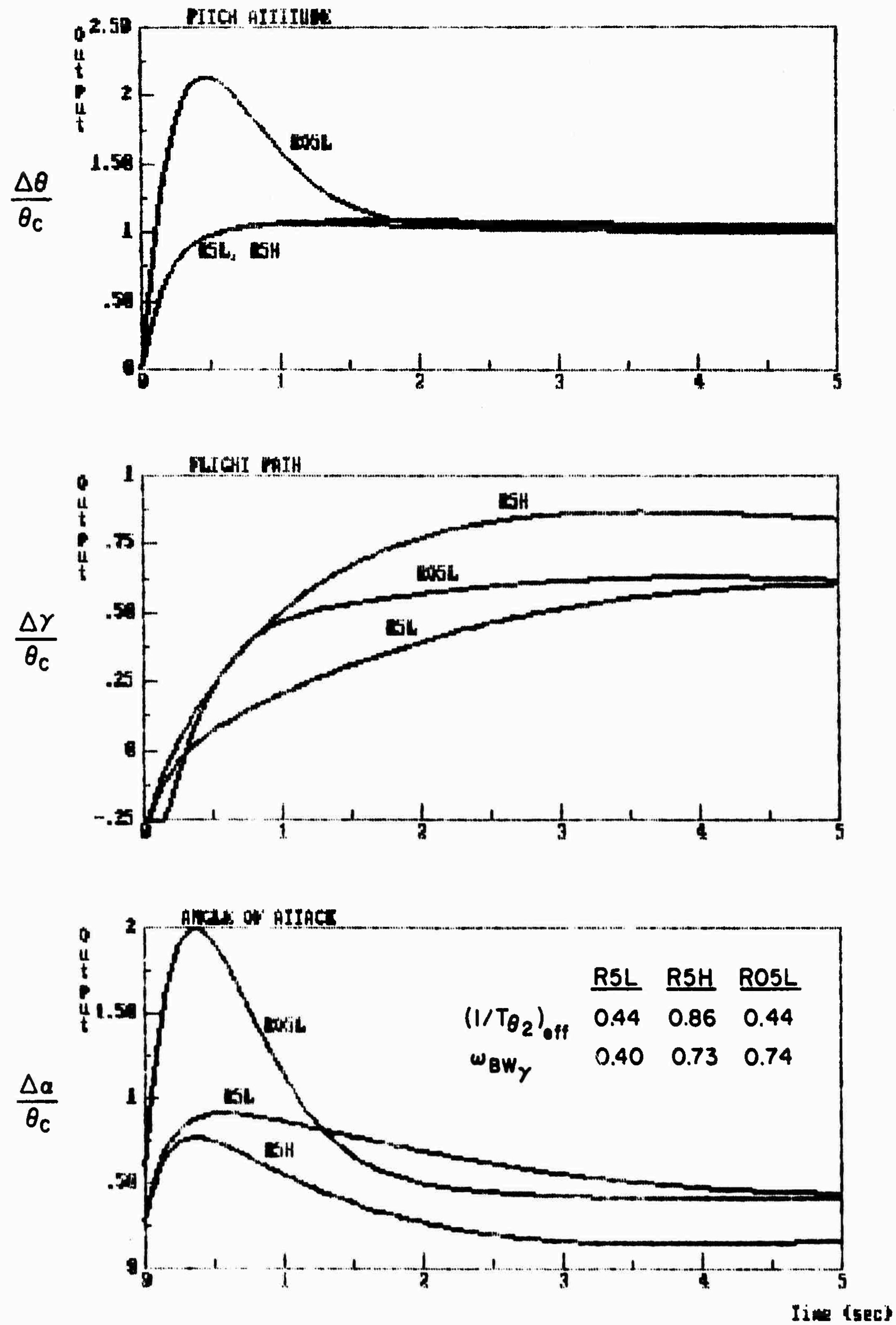


Figure 33. Effect of Pitch Rate Overshoot on RCAH Systems. ω_{BW_θ} = 5 rad/sec

Configurations R5H and R05L would be considered very similar, in terms of Cooper-Harper ratings, by a pilot.

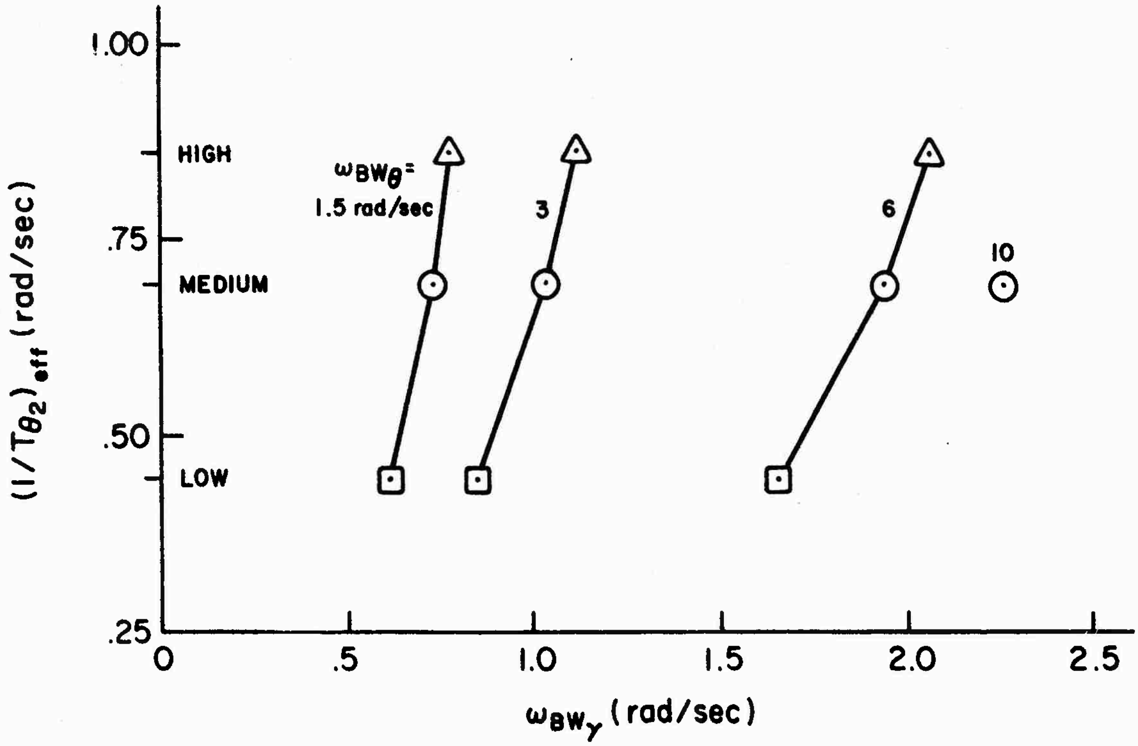
5. ω_{BW_γ} versus $(1/T_{\theta_2})_{eff}$

The parameter $(1/T_{\theta_2})_{eff}$ is used throughout this report as a candidate parameter for defining flight path bandwidth. As defined in Section III, it is a measure of the lag between flight path and pitch attitude, and thus represents the rapidity with which γ follows θ for a series pilot control scheme. However, it has been shown in Section IV to not be as descriptive as the direct bandwidth of flight path-to-longitudinal controller, ω_{BW_γ}. It is also clear from the discussion earlier in this section that, while $(1/T_{\theta_2})_{eff}$ has an effect on flight path bandwidth, it is not the only, or necessarily the dominant, factor.

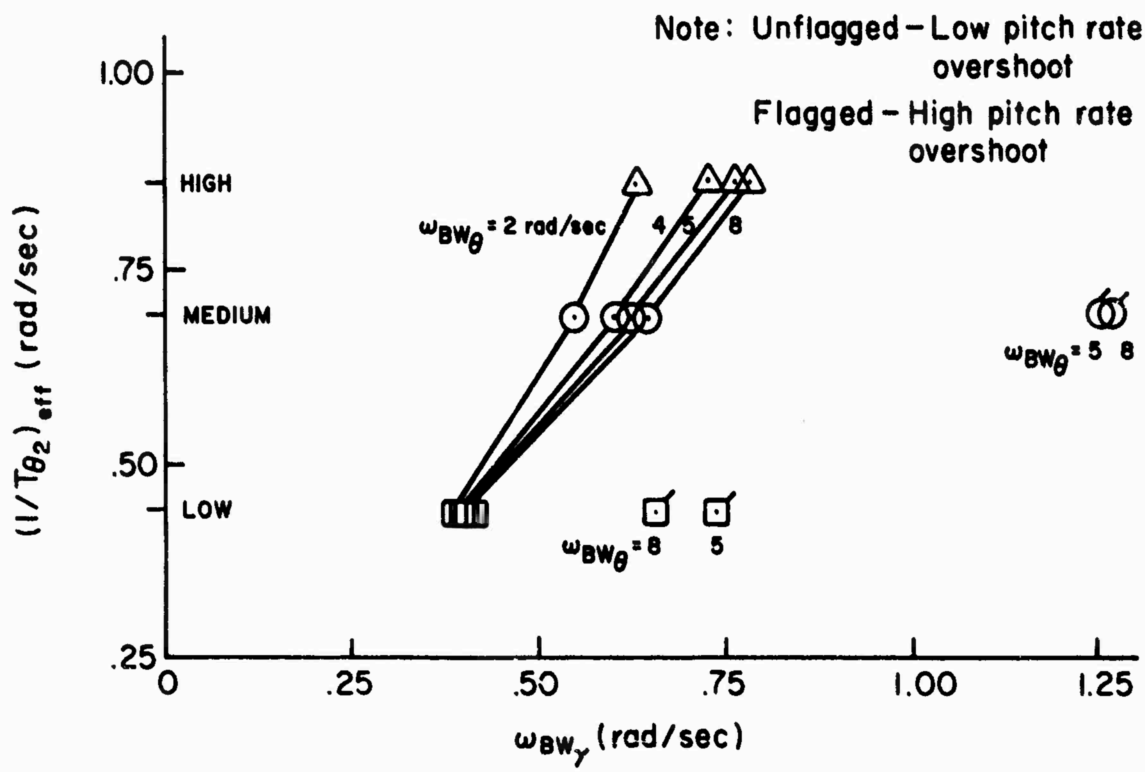
The relationship between ω_{BW_γ} and $(1/T_{\theta_2})_{eff}$ for the ACAH and RCAH configurations of Appendix B is illustrated in Figure 34. These plots simply confirm observations made above: the most important determinant in ω_{BW_γ} for ACAH systems is pitch attitude bandwidth, while $(1/T_{\theta_2})_{eff}$ dominates for RCAH systems — as long as pitch rate overshoot is minimal $[1/T_q >> (1/T_{\theta_2})_{eff}$ or $(1/T_{\theta_2})_{eff}$ is large]. This does not, of course, invalidate $(1/T_{\theta_2})_{eff}$ as a criterion: whenever the pilot is controlling flight path with attitude (the series pilot control structure), $(1/T_{\theta_2})_{eff}$ is important and ω_{BW_γ} is not; conversely, for parallel control of flight path and attitude, the direct measurement of ω_{BW_γ} is more meaningful. Hence, both parameters are of value, and Level 1 values of both should always assure Level 1 path response.

6. Flight Path/Attitude Relationship

In Section III, the parameter $\Delta\gamma_{max}/\Delta\theta_{ss}$ is recommended as a control power requirement; i.e., a certain minimum flight path change per unit pitch attitude change must be achievable. This parameter was first proposed in Reference 10 as a flare control limit, and there has been little experience with the parameter since. While such a requirement is certainly reasonable, there is some justification for revising the definition. For example, most of the configurations of Appendix B have



a) ACAH Response-Types



b) RCAH Response-Types

Figure 34. Relationship Between ω_{BW_γ} and $(1/T_{\theta_2})_{eff}$

a very low-frequency pole that results in a slight drift in the time response of pitch attitude to a longitudinal control input (step for ACAH, pulse for RCAH). For two of the very backsided cases (A6MG3 and A6HG3), this pole is actually unstable (divergent), resulting in a divergent attitude response. However, in all of these cases, it takes from ten seconds to several minutes for these low-frequency effects to manifest themselves -- far beyond the time the pilot is concerned about.

The issue, therefore, is in the use of "steady state" pitch attitude as a normalizing parameter for $\Delta\gamma_{max}/\Delta\theta_{ss}$, compared to, for example, the value at ten seconds or at the time $\Delta\gamma_{max}$ is attained. Since this is basically a flare criterion, such shorter time intervals would certainly be more representative, especially for conventional aircraft (i.e., no attitude hold).

This is an area deserving further research; at the present time, however, there is insufficient data to develop an alternative definition for $\Delta\gamma_{max}/\Delta\theta_{ss}$.

7. Flight Path Stability

Several ACAH configurations in Appendix B have been designed to validate the MIL-F-8785C limits on flight path stability, defined by $d\gamma/dV$ (in units of deg/kt). In Reference 3 an alternative parameter, t_{rev}, based on the time flight path reverses sign following a control input, was recommended. Figure 35 shows the time histories of these cases for a step control input (all cases are ACAH). In this figure, responses are labeled either as "A6L," "A6M," etc., or as "A6LG3," etc. The cases without a "Gn" suffix have Level 1 flight path stability, $d\gamma/dV < 0$; for the "Gn" cases, the value of n reflects the level of $d\gamma/dV$: for G1, $d\gamma/dV = 0.06$ deg/kt, etc., following the Levels 1, 2, and 3 limits of MIL-F-8785C. The single G4 case, A6HG4, has $d\gamma/dV = 1.0$ deg/kt -- far beyond the Level 3 limit. All of these cases should be evaluated in a simulation or flight environment, and each with varying engine time delays and with autothrottles. Figure 36 documents the characteristics of the variation cases on a crossplot of $d\gamma/dV$ vs. t_{rev}. As this figure shows, the two parameters are closely related for the configurations

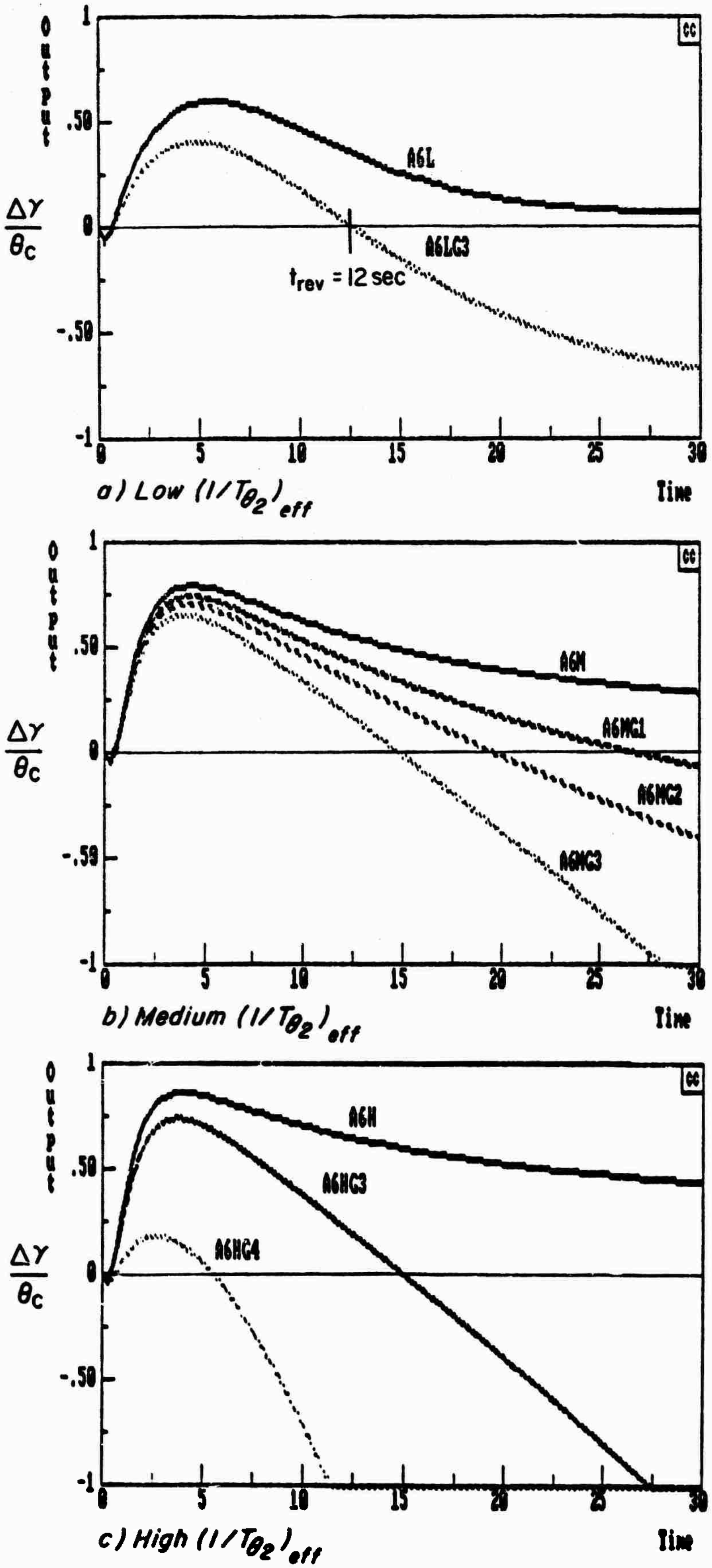


Figure 35. Step Response of Flight Path Angle Change for Configurations Developed to Evaluate Flight Path Stability

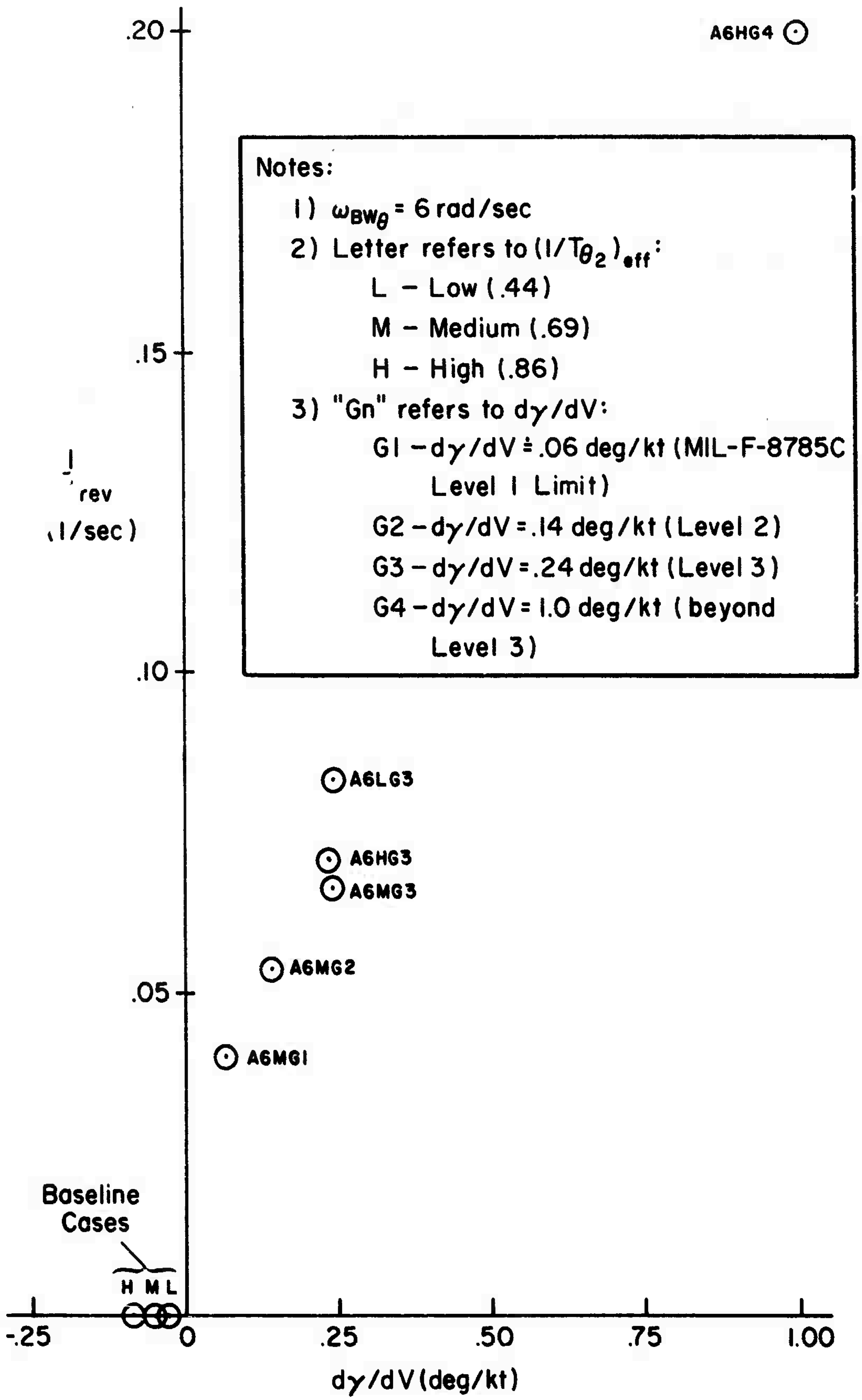


Figure 36. Flight Path Stability Variation Cases

chosen, so either parameter can be used to define flight path stability for these cases. Reference 3 contains a more thorough discussion of both parameters, and shows cases for which $d\gamma/dV$ and t_{rev} are not so closely related.

C. LATERAL-DIRECTIONAL CRITERIA

1. Overview

There is no discussion of lateral-directional handling qualities criteria for STOL aircraft are not developed in this report because there is essentially no quantitative information for developing, refining, or validating such criteria. This was the case when Reference 3 was written and, unlike the longitudinal axis, where at least a few experimental programs have been conducted recently, no studies of lateral-directional requirements for STOLs have been performed since Reference 3 was released. References 29 and 30 contain a limited amount of data for STOL transports, but there is insufficient information to develop or validate lateral-directional criteria for STOL aircraft.

Because the lateral-directional response characteristics of STOLs are basically the same as those of conventional aircraft (i.e., differences such as "powered-lift" vs. "nonpowered-lift," and "frontside" vs. "backside," do not occur in the lateral-directional axes), it is reasonable to expect that similar criteria can be applied, with some expectation that the limits of such criteria may be tightened for precision STOL approaches and landings.

In this subsection, we will review potential lateral-directional handling qualities criteria, and compare the lateral-directional variation cases of Appendix B with the current limits of each of these criteria. We consider these to be the most promising criteria and the most appropriate cases for validating the criteria.

2. Candidate Lateral-Directional Handling Qualities Criteria

The following criteria from MIL-F-8785C, MIL-F-83300, and elsewhere, apply to STOLs. For specific wording and application of the criteria, the reader should consult the appropriate specification and user's guide.

a. Roll Control Sensitivity - $\phi_{t=1}/F_{as}$ (deg/lb)

This is the ratio of bank angle at 1 sec to the force required for a step lateral control input. Recommended values for ϕ/F_{as} are given in References 1 and 32 and are shown in Table 3.

b. Time to Roll 30 Degrees - $t_{\phi=30^0}$ (seconds)

This is defined as the time taken for the bank angle (ϕ) to reach 30° after a full-scale step lateral stick input. The requirements are given in References 1 and 32 and are reproduced in Table 4.

c. Dutch Roll Frequency and Damping - ζ_d, ω_d

Limits on the Dutch roll frequency and damping from References 1 and 32 are given in Table 5.

d. Roll Mode Time Constant - T_R (seconds)

Reference 32 sets upper limits on the roll mode as indicated in Table 6.

e. Spiral Mode Time Constant - T_s (seconds)

Limits on the spiral mode are given in Table 7 from Reference 32 in terms of time to double amplitude, T_2, where $T_2 = -0.693\ T_s$.

TABLE 3. RECOMMENDED MAXIMUM ROLL CONTROL SENSITIVITY (FROM MIL-F-8785C)

LEVEL	FLIGHT PHASE CATEGORY	MAXIMUM SENSITIVITY (deg in 1 sec)/lb
1	A	15.
	C	7.5
2	A	25.
	C	12.5

TABLE 4a. ROLL PERFORMANCE FOR CLASS I AND II AIRPLANES (FROM MIL-F-8785C)
Time to Achieve the Following Bank Angle Change (Seconds)

CLASS	LEVEL	CATEGORY A		CATEGORY B		CATEGORY C	
		60 deg	45 deg	60 deg	45 deg	30 deg	25 deg
I	1	1.3		1.7		1.3	
I	2	1.7		2.5		1.8	
I	3	2.6		3.4		2.6	
II-L	1		1.4		1.9	1.8	
II-L	2		1.9		2.8	2.5	
II-L	3		2.8		3.8	3.6	
II-C	1		1.4		1.9		1.0
II-C	2		1.9		2.8		1.5
II-C	3		2.8		3.8		2.0

TABLE 4b. ROLL PERFORMANCE FOR CLASS III AIRPLANES
(FROM MIL-F-8785C)
Time to Achieve 30 deg Bank Angle Change (Seconds)

LEVEL	SPEED RANGE	CATEGORY A	CATEGORY B	CATEGORY C
1	L	1.8	2.3	2.5
	M	1.5	2.0	2.5
	H	2.0	2.3	2.5
2	L	2.4	3.9	4.0
	M	2.0	3.3	4.0
	H	2.5	3.9	4.0
3	ALL	3.0	5.0	6.0

TABLE 4c. ROLL PERFORMANCE FOR CLASS IV AIRPLANES
(FROM MIL-F-8785C)
Time to Achieve the Following Bank Angle Change (Seconds)

LEVEL	SPEED RANGE	CATEGORY A			CATEGORY B	CATEGORY C
		30 deg	50 deg	90 deg	90 deg	30 deg
1	VL	1.1			2.0	1.1
	L	1.1			1.7	1.1
	M			1.3	1.7	1.1
	H		1.1		1.7	1.1
2	VL	1.6			2.8	1.3
	L	1.5			2.5	1.3
	M			1.7	2.5	1.3
	H		1.3		2.5	1.3
3	VL	2.6			3.7	2.0
	L	2.0			3.4	2.0
	M			2.6	3.4	2.0
	H		2.6		3.4	2.0

TABLE 5. RECOMMENDED MINIMUM DUTCH ROLL FREQUENCY AND DAMPING (FROM MIL-F-8785C)

LEVEL	FLIGHT PHASE CATEGORY	CLASS	Min ζ_d*	Min $\zeta_d\omega_d$* (rad/sec)	Min ω_d (rad/sec)
1	A (CO and GA)	IV	0.4	0.4	1.0
	A	I, IV II, III	0.19 0.19	0.35 0.35	1.0 0.4
	B	All	0.08	0.15	0.4
	C	I, II-C, IV	0.08	0.15	1.0
		II-L, III	0.08	0.10	0.4
2	All	All	0.02	0.05	0.4
3	All	All	0	--	0.4

*The governing damping requirement is that yielding the larger value of ζ_d, except that a ζ_d of 0.7 is the maximum required for Class III.

When $\omega_d^2|\phi/\beta|_d$ is greater than 20 $(\text{rad/sec})^2$, the minimum $\zeta_d\omega_d$ should be increased above the $\zeta_d\omega_d$ minimums listed in Table 5 by:

$$\text{Level 1:} \quad \Delta\zeta_d\omega_d = 0.014(\omega_d^2|\phi/\beta|_d - 20)$$

$$\text{Level 2:} \quad \Delta\zeta_d\omega_d = 0.009(\omega_d^2|\phi/\beta|_d - 20)$$

$$\text{Level 3:} \quad \Delta\zeta_d\omega_d = 0.005(\omega_d^2|\phi/\beta|_d - 20)$$

with ω_d in rad/sec.

TABLE 6. MAXIMUM ROLL-MODE TIME CONSTANT, SECONDS (FROM MIL-F-8785C)

FLIGHT PHASE CATEGORY	CLASS	LEVEL 1	LEVEL 2	LEVEL 3
A	I, IV II, III	1.0 1.4	1.4 3.0	
B	All	1.4	3.0	10
C	I, II-C, IV II-L, III	1.0 1.4	1.4 3.0	

TABLE 7. SPIRAL STABILITY -- MINIMUM TIME TO DOUBLE AMPLITUDE (FROM MIL-F-8785C)

FLIGHT PHASE CATEGORY	LEVEL 1	LEVEL 2	LEVEL 3
A & C	12 sec	8 sec	4 sec
B	20 sec	8 sec	4 sec

f. Roll-Sideslip Coupling - $|\Delta\beta/\phi_1|$

Roll-sideslip coupling is calculated as the ratio of the maximum change in sideslip angle (occurring within two seconds) to the first roll angle peak (ϕ_1) (see Figure 37) following a pulse lateral controller input. Requirements are given in Reference 33 and are reproduced in Figure 38a. The ratio $|\Delta\beta/\phi_1| \times |\phi/\beta|_d$ accounts for high $|\phi/\beta|_d$; requirements are given in Reference 33 and are shown in Figure 38b. These requirements are considered to be more appropriate and less subject to interpretation than the more familiar $\Delta\beta/k$ parameter of MIL-F-8785C (see, for example, discussions in References 1 and 34).

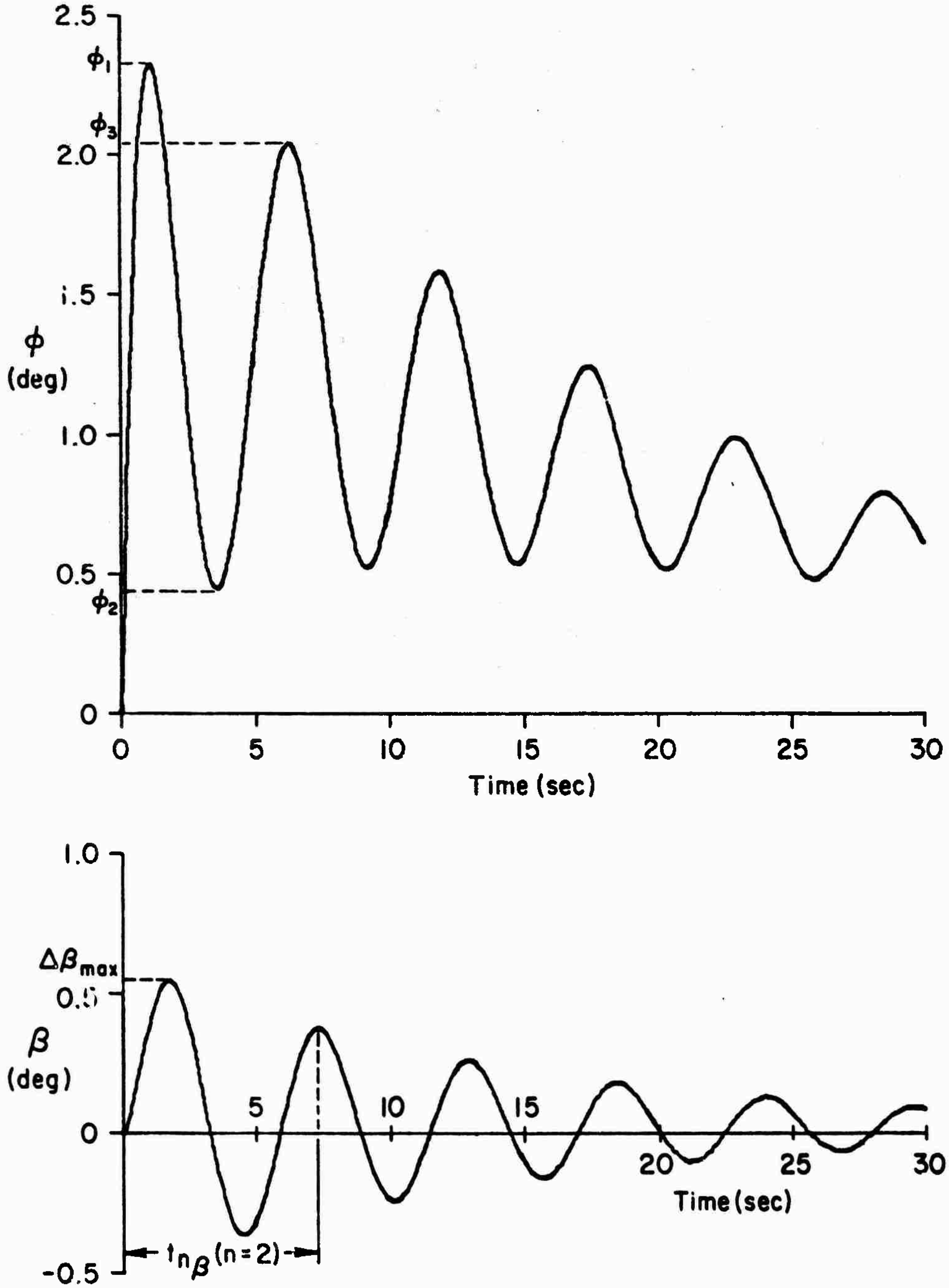
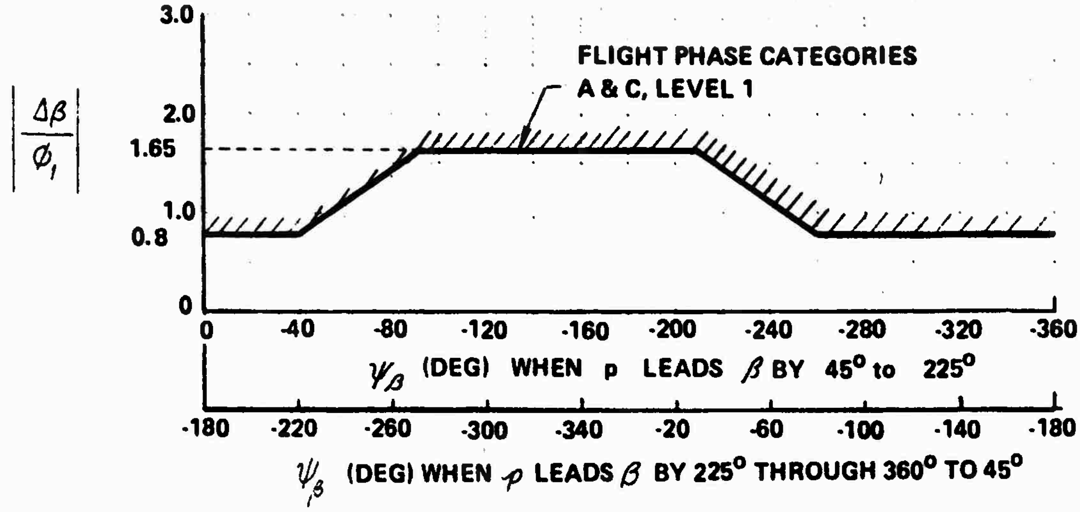
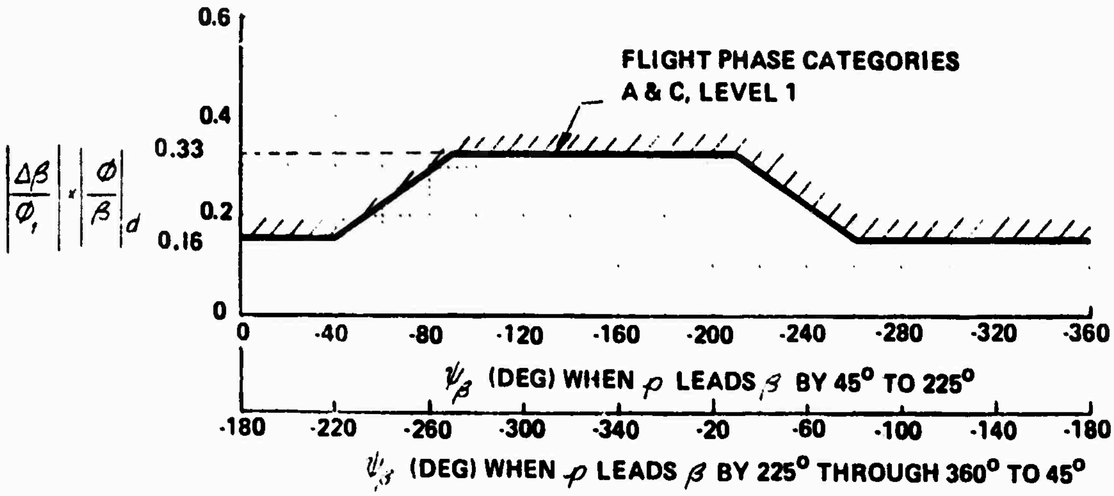


Figure 37. Roll Angle and Sideslip Angle Response to a Unit Impulse in Lateral Stick



a) BOUNDARY FOR $\left|\frac{\Delta\beta}{\phi_1}\right|$



b) BOUNDARY FOR $\left|\frac{\Delta\beta}{\phi_1}\right| \times \left|\frac{\phi}{\beta}\right|_d$

Figure 38. Sideslip Excursion Limitations (from MIL-F-83300)

g. Lateral Oscillation Parameter - ϕ_{osc}/ϕ_{av}

This parameter is defined as shown below (see Figure 37).

$$\frac{\phi_{osc}}{\phi_{av}} = \frac{\phi_1 + \phi_3 - 2\phi_2}{\phi_1 + \phi_3 + 2\phi_2} \qquad \zeta_d < 0.2$$

$$\frac{\phi_{osc}}{\phi_{av}} = \frac{\phi_1 - \phi_2}{\phi_1 + \phi_2} \qquad \zeta_d > 0.2$$

Requirements are given in Reference 32 and are shown in Figure 39.

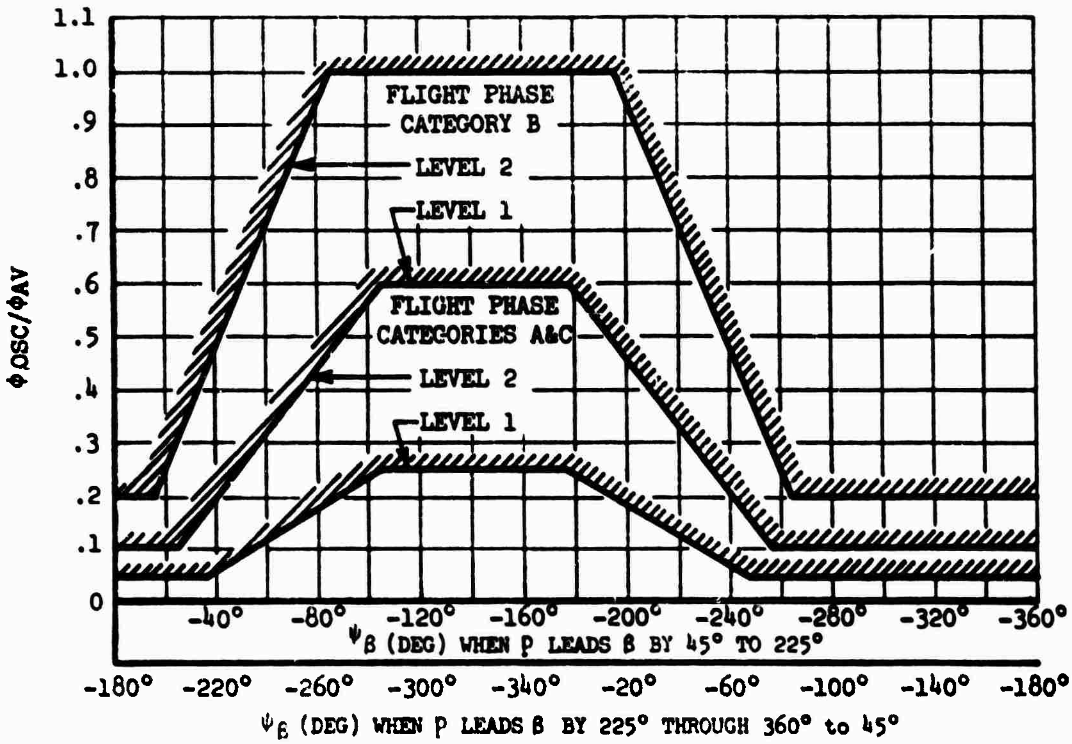


Figure 39. Bank Angle Oscillation Limitations
(from MIL-F-8785C)

h. Alternative Lateral Oscillation Parameter - ϕ_{osc}/ϕ_1

This is defined as

$$\frac{\phi_{osc}}{\phi_1} = \frac{\phi_1 + \phi_3 - 2\phi_2}{2\phi_1} \qquad \zeta_d < 0.2$$

$$\frac{\phi_{osc}}{\phi_1} = \frac{\phi_1 - \phi_2}{2\phi_1} \qquad \zeta_d > 0.2$$

No requirements exist for this parameter. It is recommended in Reference 34 as an alternative to ϕ_{osc}/ϕ_{av} because it is less sensitive to the effects of the spiral mode.

i. Turn Coordination Parameters - $\delta'_{rp}(3)$ and μ

The yaw-to-roll crossfeed parameters are calculated using the rules stated in Reference 1. The parameters are dependent on the value of $N'_{\delta_a}/L'_{\delta_a}$, i.e.,

$$\delta'_{rp}(3) \quad \text{if} \quad |N'_{\delta_a}/L'_{\delta_a}| < 0.03$$

$$\mu \quad \text{if} \quad |N'_{\delta_a}/L'_{\delta_a}| > 0.07$$

$$\text{both } \delta'_{rp}(3) \text{ and } \mu \text{ if } 0.03 < |N'_{\delta_a}/L'_{\delta_a}| < 0.07$$

Requirements for these parameters are presented in Reference 1 and are shown in Figure 40.

3. Development of Lateral-Directional Variation Cases

Appendix B documents the characteristics of 88 separate lateral-directional cases that were developed to cover the full range of the flying qualities criteria outlined above. The state of the data base for lateral-directional STOL characteristics is considerably more limited than that for CTOLs, with a critical need in the short term for fundamental information on what the boundaries of the existing criteria

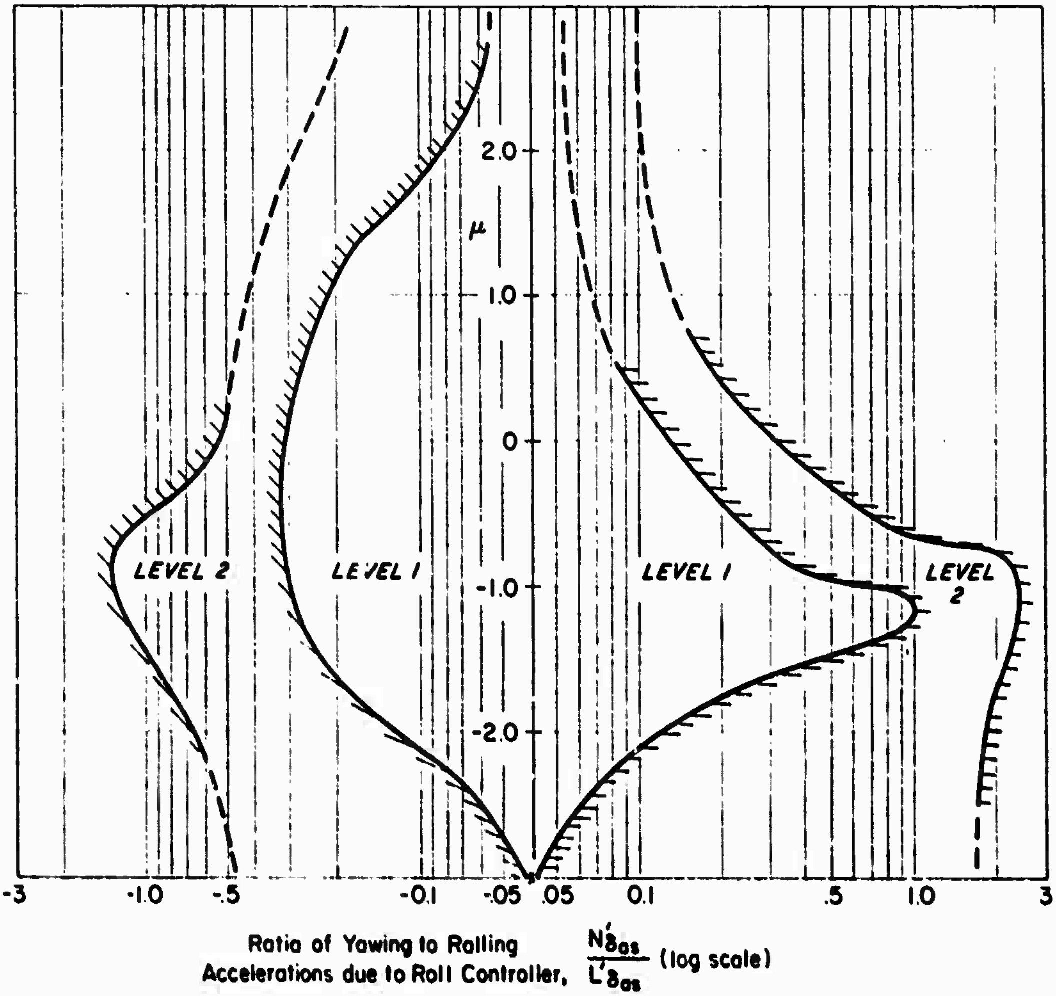


Figure 40a. Crossfeed Parameter Boundaries -- $\left|\frac{N'_{\delta_a}}{L'_{\delta_a}}\right| > 0.07$

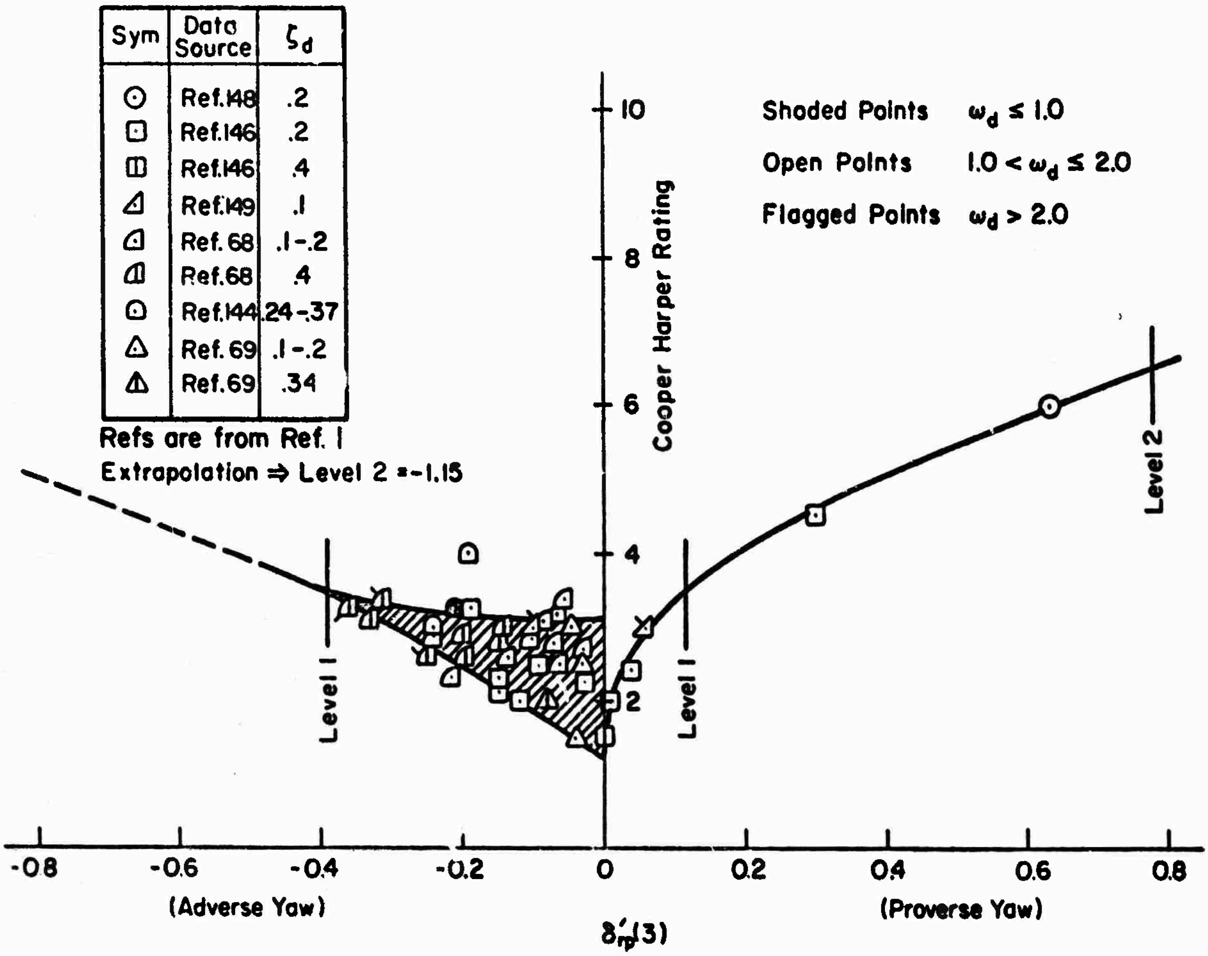


Figure 40b. Pilot Rating Correlations When $\left|N'_{\delta_{as}}/L'_{\delta_{as}}\right| < 0.07$

should be. The logical next step would then be investigation of the more esoteric issues -- response-types, time delay effects, attitude hold, etc.

The basic variations in dynamics were made by changing aerodynamic stability and control derivatives. A roll-yaw crossfeed shaping function was utilized to accomplish the modification of turn coordination characteristics.

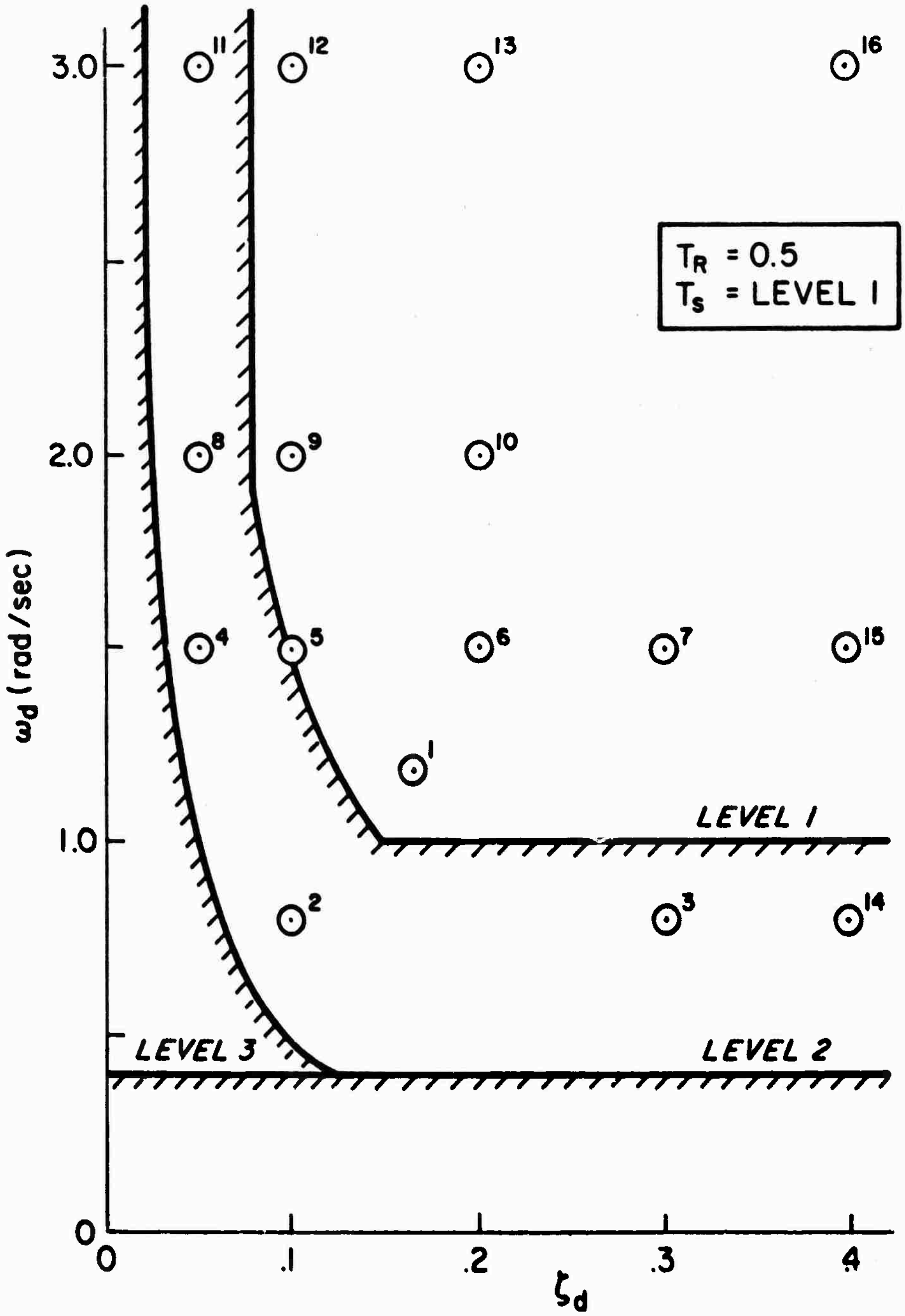
Table B-4 of Appendix B summarizes the various handling qualities parameters for the lateral variation cases. As this table indicates, the first sixteen cases were devised to evaluate variations in Dutch roll frequency and damping. Cases 17 through 20 are roll mode variations, and Cases 43 through 52 are control power (L_{δ_a}) variations. The rest of the cases represent variations in turn coordination: Cases 21 through 38 have a nominal value of roll-sideslip ratio, $|\phi/\beta|_d$; Cases 21A through 38A and 21B through 38B have low and high values of $|\phi/\beta|_d$, respectively. Cases 39 through 42 are also turn coordination variations with a very low value of $N'_{\delta_a}/L'_{\delta_a}$.

The following discussion will compare the handling qualities characteristics of these cases (from Appendix B) with the candidate criteria.

4. Comparisons with Criteria

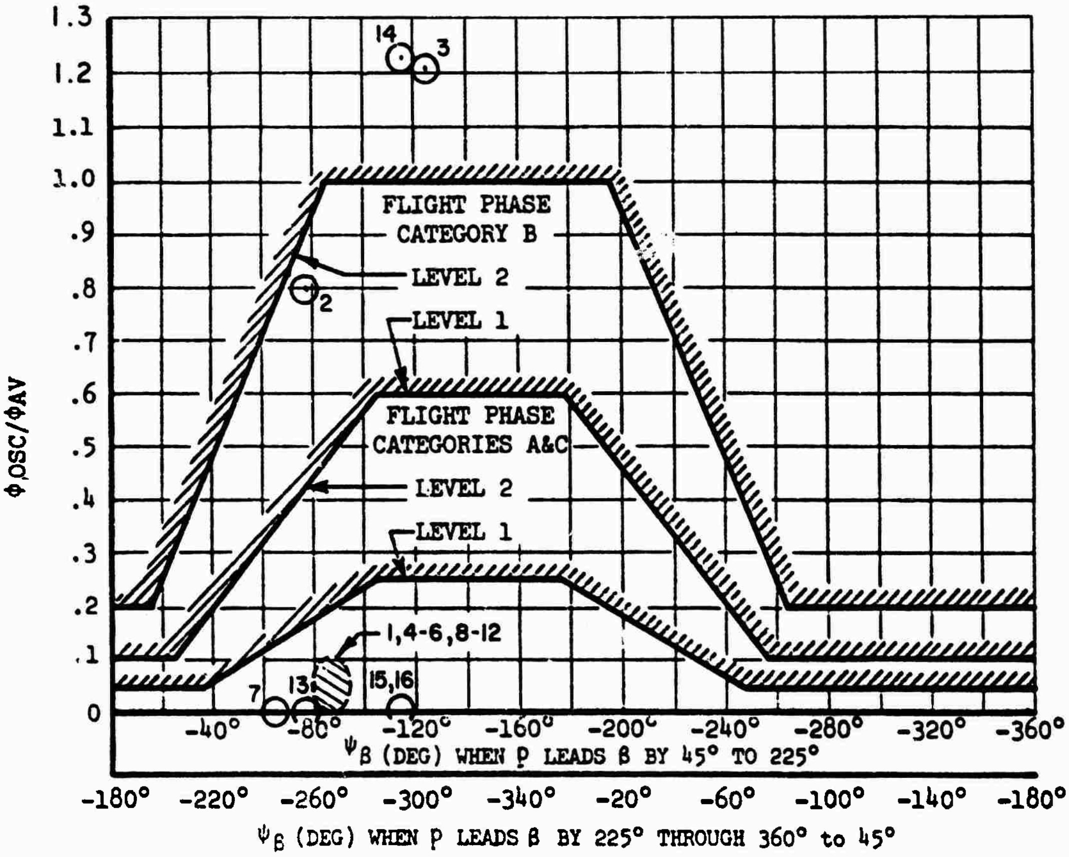
a. Dutch Roll Variations

Cases 1 through 16 were devised to evaluate a range of Dutch roll natural frequencies and damping ratios; as a result, the spiral mode was Level 1 ($T_S \doteq \infty$), and the roll mode kept approximately constant at $1/T_R \doteq 2$ rad/sec. Time-to-bank and control sensitivity values were either Level 1 or only marginally Level 2 (i.e., MIL-F-8785C requires $t_{\phi=30^0} \leq 1.1$ sec, and as Table B-4 shows, this parameter ranged between 1.13 and 1.20 sec for these cases). Figure 41 summarizes these cases in terms of Dutch roll, bank angle oscillation, and sideslip excursion characteristics.



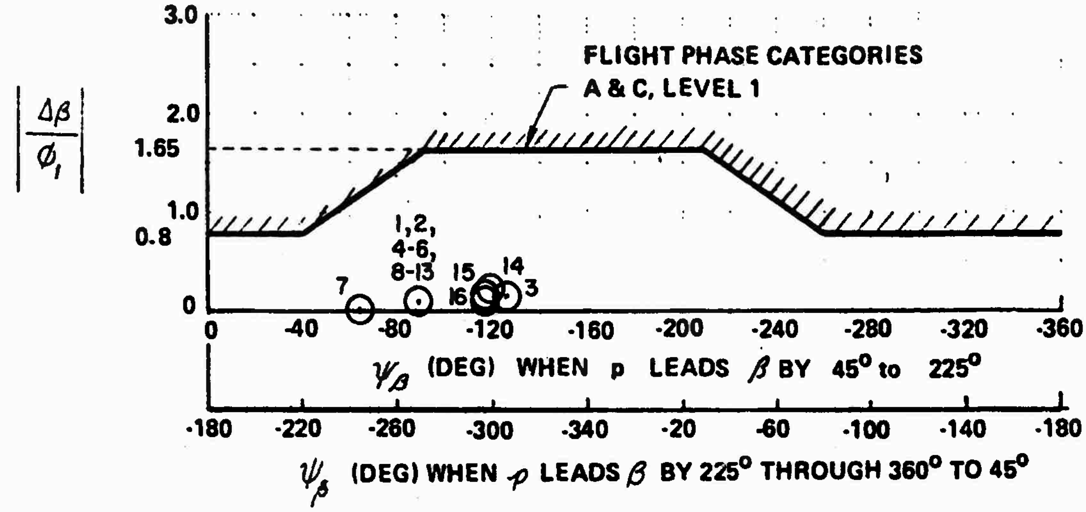
a) Dutch Roll Requirements

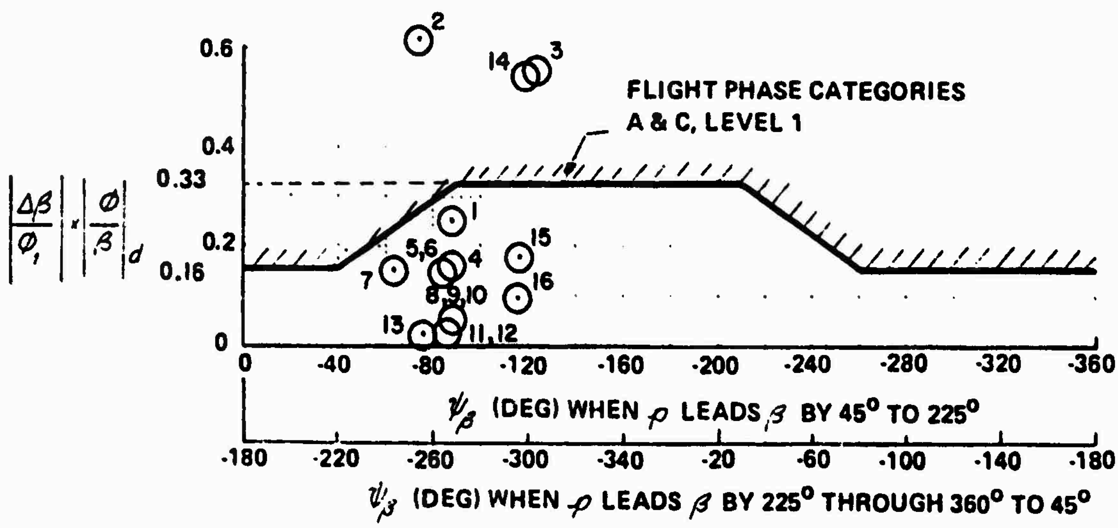
Figure 41. Characteristics of Dutch Roll Variation Cases (Appendix B, Cases 1-16)



b) Bank Angle Oscillation Limitations

Figure 41. (Continued)





c) Sideslip Excursion Limitation Requirements

Figure 41. (Concluded)

Only three cases in Figure 41 lie in the current Level 2 or 3 boundaries: Cases 2, 3, and 14, all with low Dutch roll frequency (these cases are Level 1 on the $|\Delta\beta/\phi_1|$ boundary, but high $|\phi/\beta|_d$ makes them Level 2 for the second sideslip excursion requirement, Figure 41c). It is expected that more stringent limits will apply due to the increased lateral precision requirements inherent to short and narrow STOL runways. Case 14 is an apparent anomaly, since it has good Dutch roll damping ($\zeta_d = 0.4$) but the highest value of ϕ_{osc}/ϕ_{av} of all the cases, Figure 41b. Case 15, with the same damping ratio but higher Dutch roll frequency (1.5 rad/sec vs. 0.8 rad/sec) has no roll oscillation. Figure 42 shows time histories of bank angle and sideslip angle for a pulse lateral stick input for Cases 14, 15, and 16 (i.e., all cases with $\zeta_d = 0.4$). As the bank angle response shows, Case 14 has $\phi_{osc}/\phi_{av} > 1$ because $\phi_2 < 0$; and for Cases 14 and 15, the ratio ϕ_{osc}/ϕ_{av} is zero because there is no second peak (ϕ_2 does not exist). In this example, Case 14 does not look significantly worse than Case 15, at least as far as ϕ_{osc}/ϕ_{av} is concerned. It is likely that Case 14 would not be acceptable in flight, but because of the very low Dutch roll frequency, not because of roll oscillations. This suggests that there is some justification for refining the definition of ϕ_{osc}/ϕ_{av}.

b. Roll Mode Variations

Five cases (Cases 1, 17, 18, 19, and 20) were designed to evaluate the limits on roll mode time constant. The following table lists the time constants and flying qualities Level (based on MIL-F-8785C, Class IV, Flight Phase Category C) for these cases.

CASE	T_R, sec	LEVEL
17	1.25	2
18	1.0	1-2
19	0.667	1
1	0.5	1
20	0.333	1

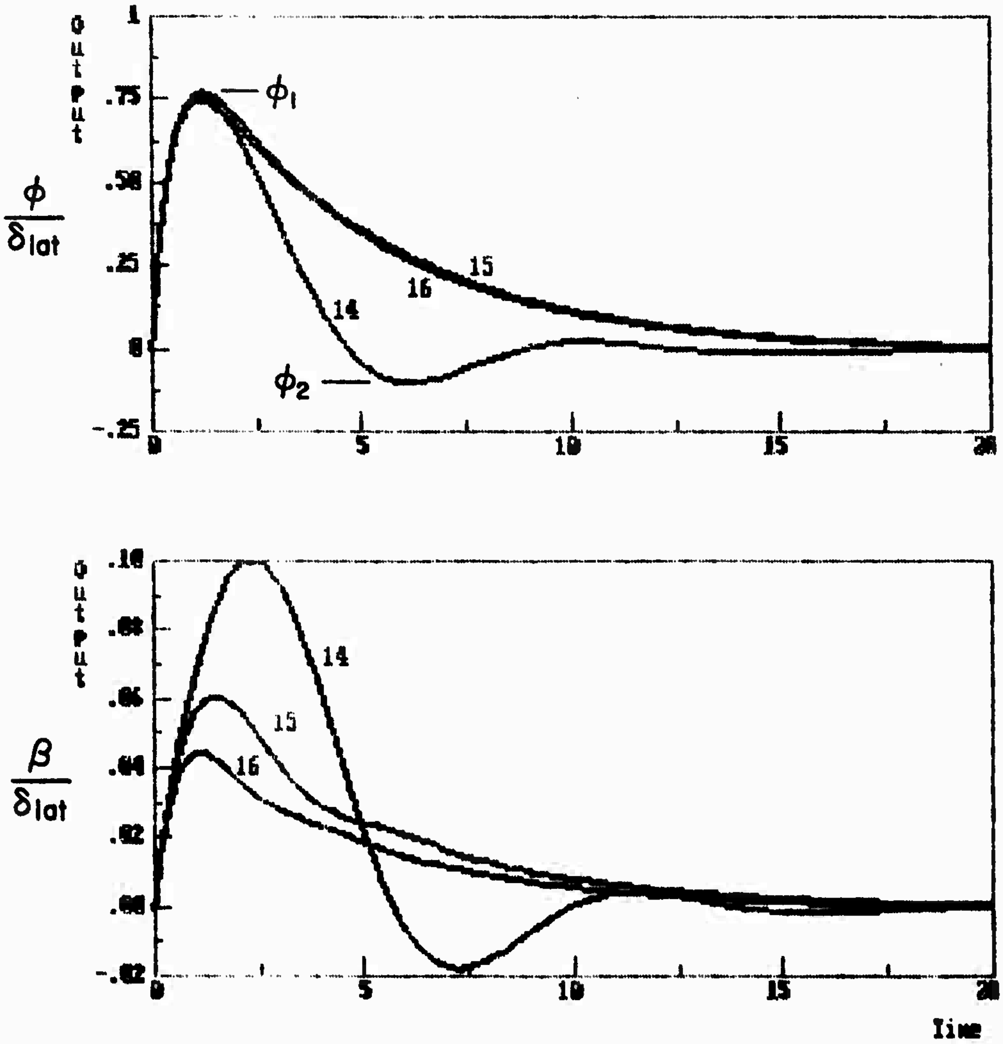


Figure 42. Time Histories of Cases 14, 15, and 16 for Pulse Lateral Stick Input

These cases are Level 1 on all the other handling qualities boundaries discussed above.

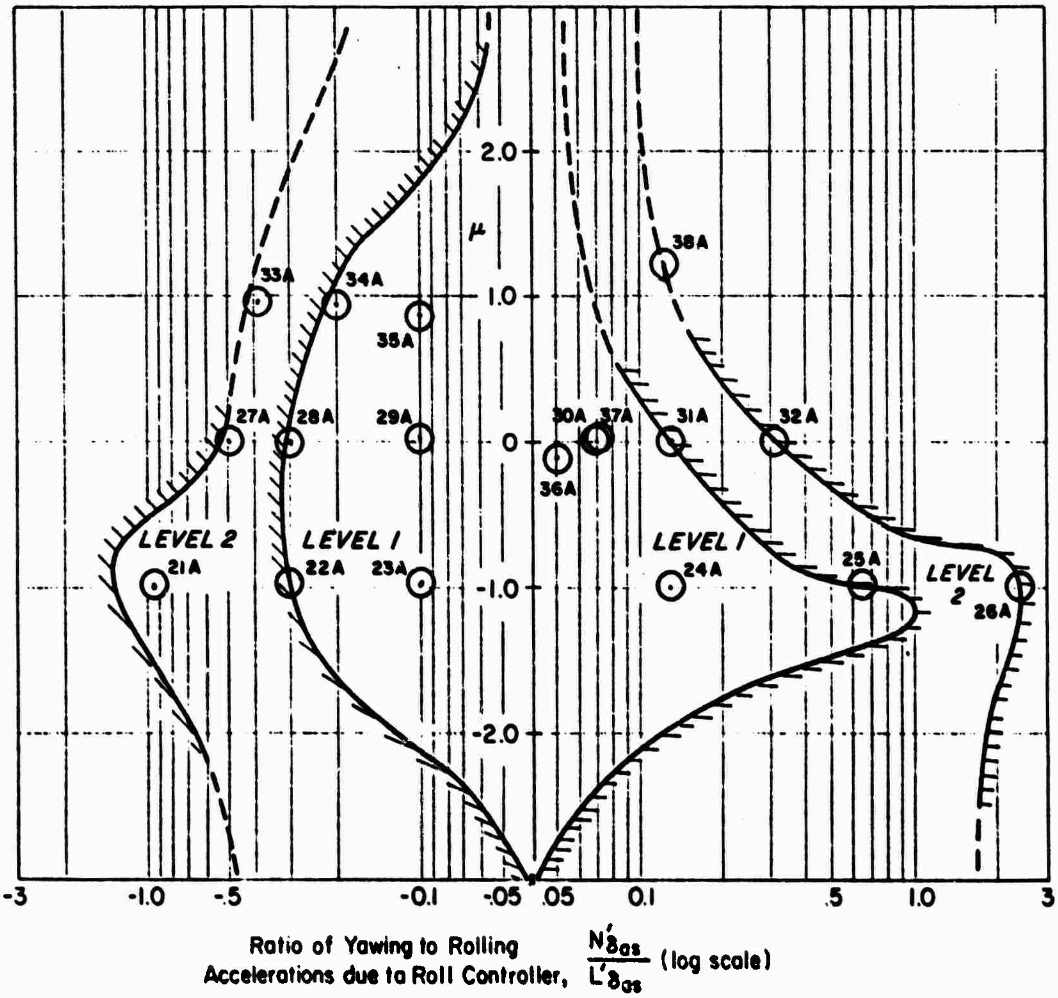
c. Turn Coordination Variations

The bulk of the lateral-directional variation cases of Appendix B are aimed at investigating the effects of imperfect turn coordination on flying qualities. Since STOL aircraft -- including proposed STOL fighters -- typically fly at quite low approach speeds, the problems associated with low-speed flight, such as adverse aileron yaw and roll-due-to-rudder, are more likely to show up.

Cases 21 through 42, 21A through 38A, and 21B through 38B encompass a wide variety of roll/yaw response characteristics. All of these cases have Level 1 values of spiral, roll, and Dutch roll modes; modification of control derivatives and use of stick-to-rudder crossfeeds produced the variations listed in Appendix B. The intent of the variations was to examine a wide range of points on the turn coordination (μ) requirement, Figure 40, with three different values of $|\phi/\beta|_d$: 2.7 (nominal), 0.9 (low), and 4.1 (high).

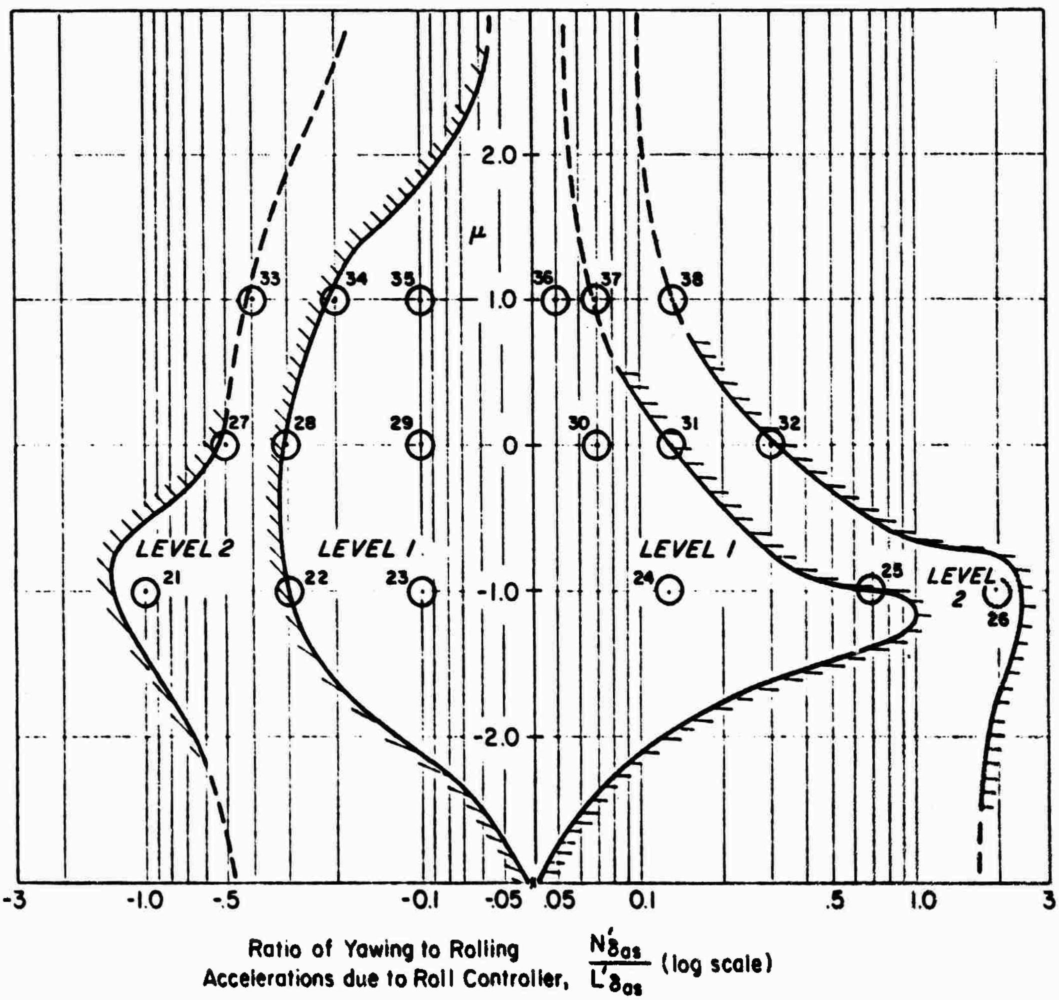
Figure 43 shows the turn coordination variation cases on the μ plot. Values of $\mu = +1$, 0, and -1 were chosen, and cases designed to be in each of the level boundaries, or on the edges of the boundaries, by varying the sign and magnitude of the ratio $N'_{\delta_a}/L'_{\delta_a}$. This results in large variations in other parameters as well, as Table B-4 shows; the most interesting of these parameters is the competing requirement on turn coordination (sideslip excursions), $|\Delta\beta/\phi_1|$ or $|\Delta\beta/\phi_1| \times |\phi/\beta|_d$, Figure 38. Figure 44 shows the cases plotted on the $|\Delta\beta/\phi_1| \times |\phi/\beta|_d$ vs. ψ_β requirement; this is most interesting since three different values of $|\phi/\beta|_d$ were used.

Symbols in Figure 44 have been shaded according to the Level limits of Figure 43: open symbols are in the Level 1 region in Figure 43, hatched symbols lie on the Level 1 limit boundary, etc. In addition, those cases that have Level 1 values of ϕ_{osc}/ϕ_{av} are marked with an asterisk. Assuming that the current limits on ϕ_{osc}/ϕ_{av}, Dutch roll



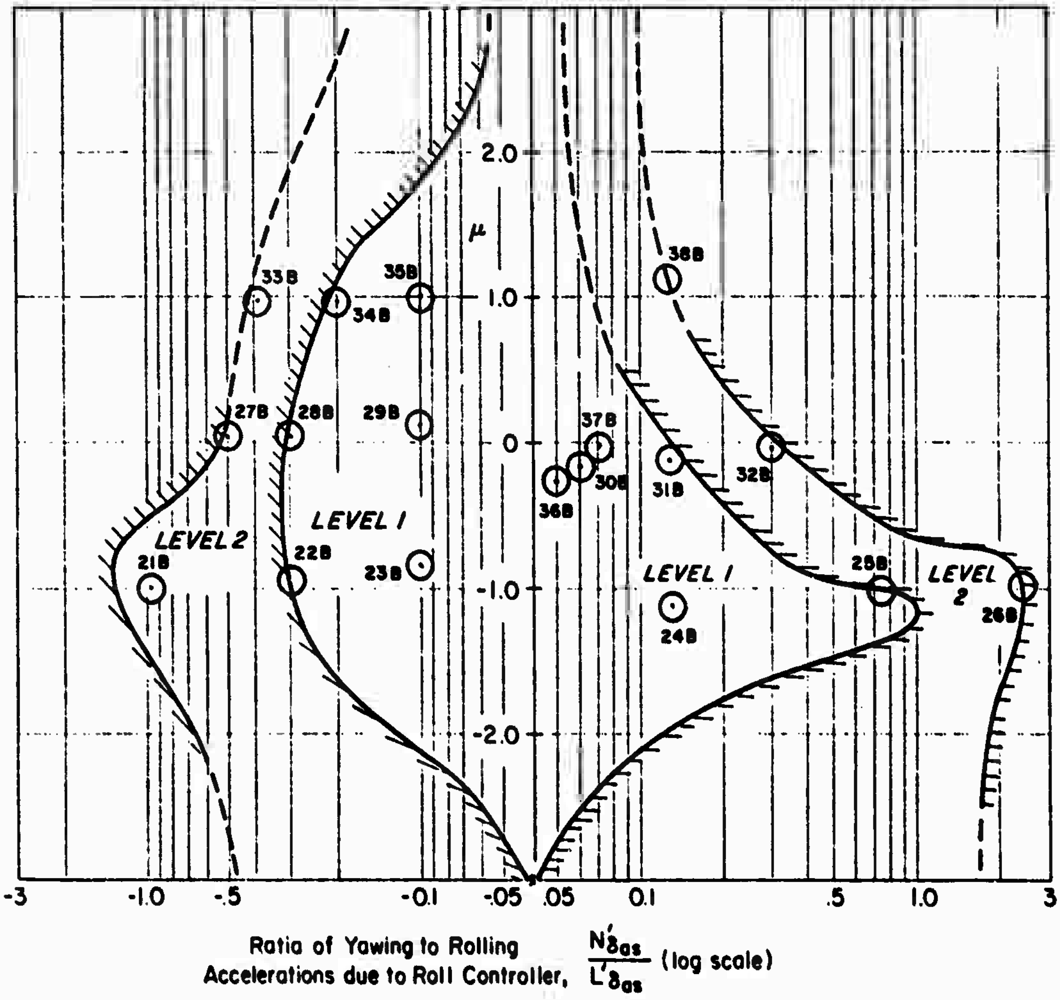
a) Low $|\phi/\beta|_d$

Figure 43. Variations in Turn Coordination



b) Nominal $|\phi/\beta|_d$

Figure 43. (Continued)



c) High $|\phi/\beta|_d$

Figure 43. (Concluded)

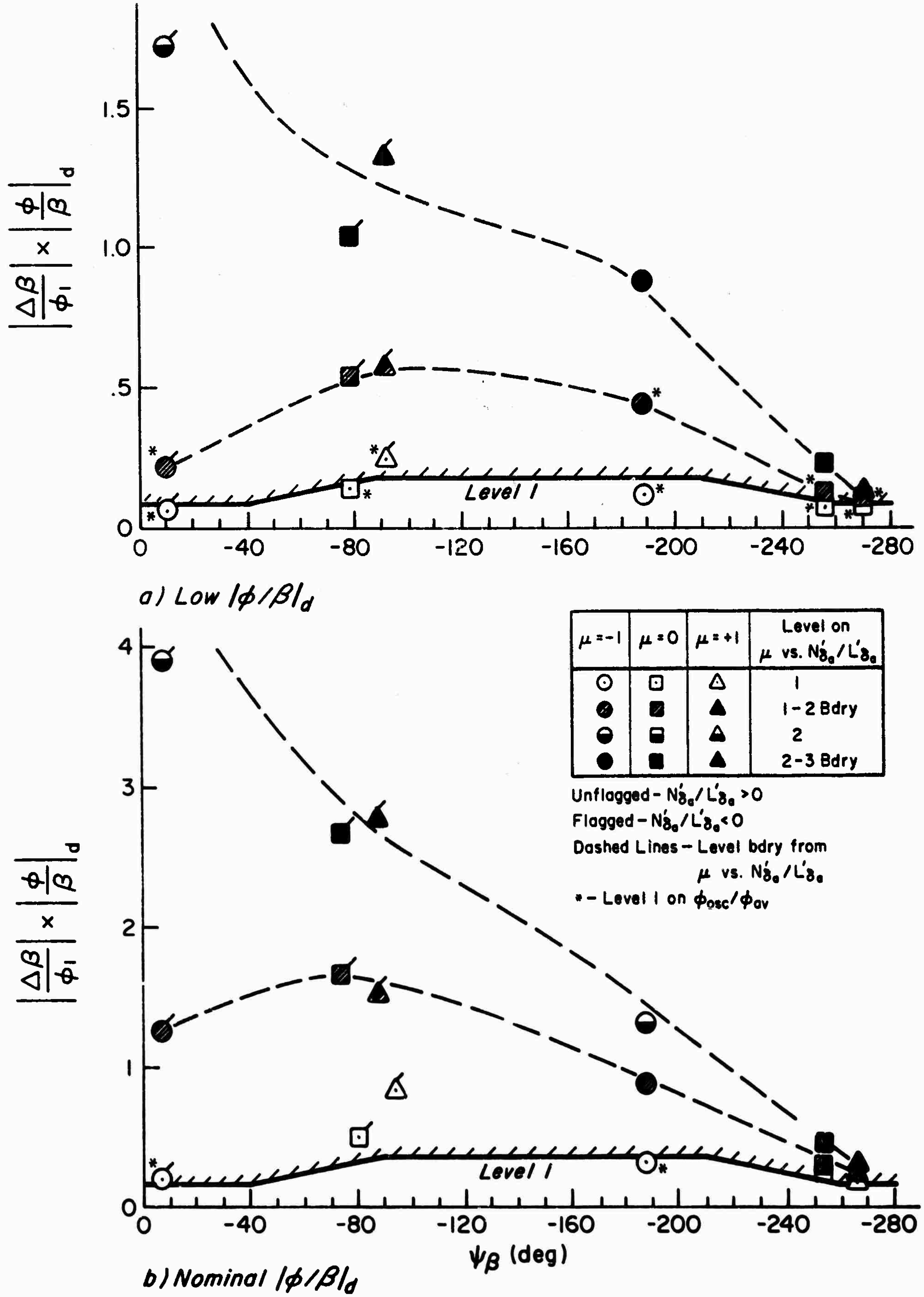
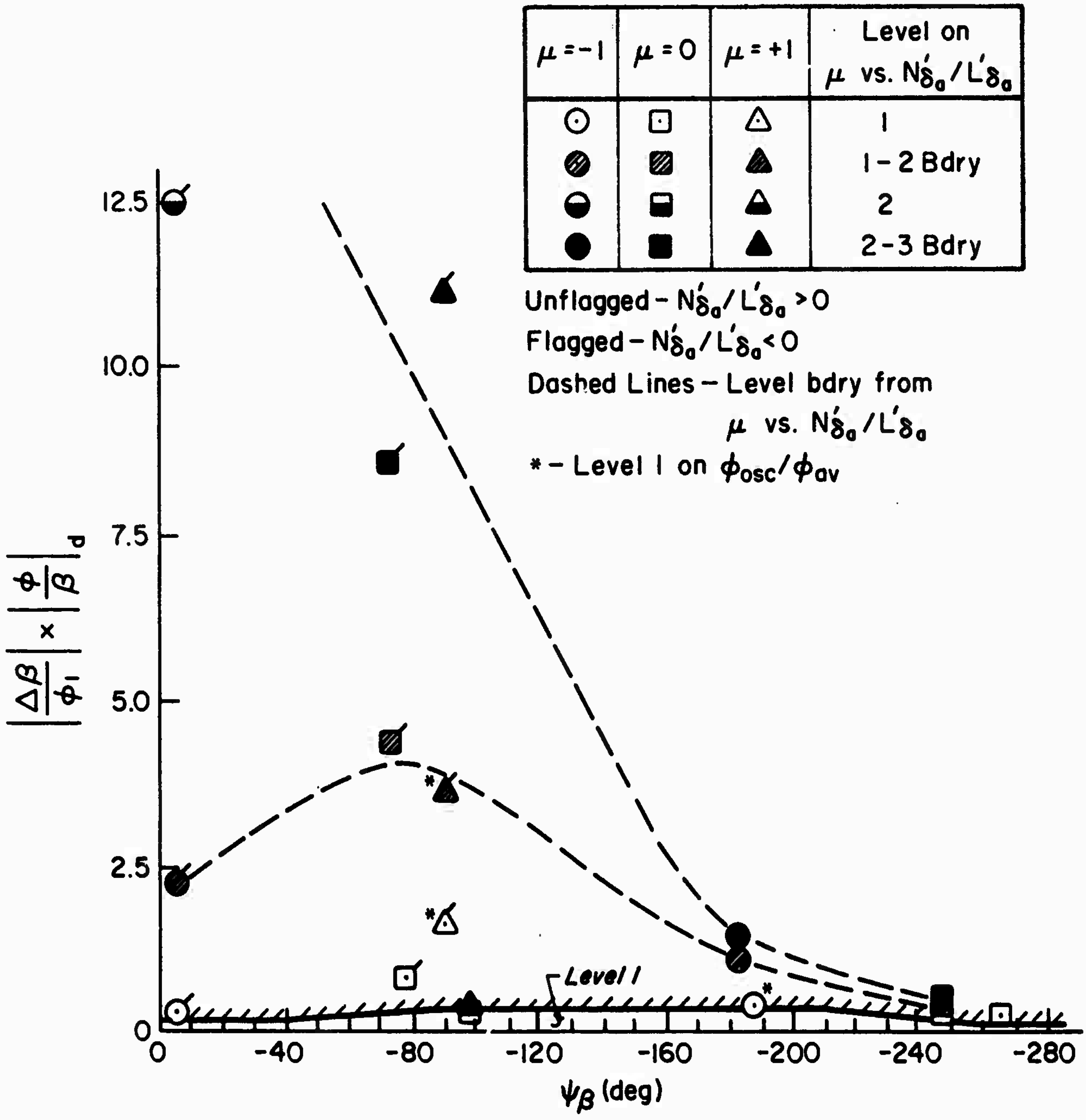


Figure 44. Sideslip Excursion Characteristics of Turn Coordination Cases



c) High $|\phi/\beta|_d$

Figure 44. (Concluded)

characteristics, etc., are applicable to STOLs, these would be the most interesting cases for a simulation or flight experiment. Several of the marked cases have quite high values of $|\Delta\beta/\phi_1| \times |\phi/\beta|_d$, yet are in the Level 1 region on the μ requirement plot, and thus these cases would resolve which of the criteria is more applicable. The dashed lines on Figure 44 represent rough mapping of the μ boundaries based upon the data points; clearly, μ allows much larger values of $|\Delta\beta/\phi_1| \times |\phi/\beta|_d$ at low values of ψ_β. In addition, the μ requirement does not disallow very large values of $|\phi/\beta|_d$.

As with all the lateral-directional criteria discussed above, it is impossible to resolve here whether the boundaries, or even the criteria themselves, are applicable to STOLs. A considerable amount of simulation or, preferably, flight research, must be performed.

SECTION VI

CONCLUSIONS

The conclusions reached in this study are summarized below.

- STOL approach and landing handling qualities requirements must account for attitude and flight path control. This may or may not require separate criteria.

- The criteria should specify the allowable Response-Types. Four Response-Types are identified for STOL approach and landings; Conventional Airplane, Rate, Rate-Command-Attitude Hold (RCAH) and Attitude-Command-Attitude-Hold (ACAH).

- ACAH was found to be the most desirable Response-Type for precision STOL landings.

- The Conventional Airplane Response-Type (identified by a step angle-of-attack response to a step longitudinal controller input) was acceptable for STOL landings, but required a higher attitude bandwidth than ACAH.

- Rate and RCAH Response-Types are generally the least desirable for precision STOL landings. However, Level 1 handling qualities can be achieved if $1/T_q \doteq 1/T_{\theta_2}$ (which makes it look like a Conventional Airplane Response-Type). This may result in an undesirably low attitude bandwidth, if $1/T_{\theta_2}$ is small (less than about .8).

- The Response-Type used during STOL approaches is not critical (all are acceptable). That is, the Response-Type requirement is driven by the landing task. This may be alleviated by building a strong enough landing gear to allow no-flare landings. However, such an alleviation was not found to be justified by the data from the LAMARS simulation (which involved no-flare landings).

- The ω_{sp} vs n/α criterion, in combination with a lower order equivalent system (LOES) fit (to the short period approximation), is utilized as a combined attitude and flight path criterion in MIL-F-8785C. This criterion is not applicable unless a Conventional Airplane Response-Type is employed. The criteria proposed herein involve bandwidth, which is not dependent on the Response-Type.

- There are substantial gaps in the database which should be filled to provide adequate supporting data for STOL handling qualities criteria.

REFERENCES

1. Hoh, Roger H., David G. Mitchell, Irving L. Ashkenas, et al., Proposed MIL Standard and Handbook -- Flying Qualities of Air Vehicles. Volume II: Proposed MIL Handbook, AFWAL-TR-82-3081, Nov. 1982.

2. Berthe, C. J., C. R. Chalk, and S. Sarrafian, Pitch Rate Flight Control Systems in the Flared Landing Task and Design Criteria Development, NASA CR-172491, Oct. 1984.

3. Hoh, Roger H., and David G. Mitchell, Tentative STOL Flying Qualities Criteria for MIL Standard and Handbook, AFWAL-TR-83-3059, June 1983.

4. Hogkinson, J., and W. J. LaManna, "Equivalent System Approaches to Handling Qualities Analysis and Design Problems of Augmented Aircraft," AIAA Paper No. 77-1122, presented at AIAA Atmospheric Flight Mechanics Conference, Hollywood, FL, 8-10 Aug. 1977.

5. Hogkinson, J., and K. A. Johnston, "Initial Results of an Inflight Simulation of Augmented Dynamics in Fighter Approach and Landing," AIAA Paper No. 79-1783, presented at AIAA Guidance and Control Conference, Boulder, CO, 6-8 Aug. 1979.

6. Hoh, Roger H., Samuel J. Craig, and Irving L. Ashkenas, Identification of Minimum Acceptable Characteristics for Manual STOL Flight Path Control. Volume I: Summary Report, FAA-RD-75-123,I, June 1976.

   Hoh, R. H., S. J. Craig, and I. L. Ashkenas, Identification of Minimum Acceptable Characteristics for Manual STOL Flight Path Control. Volume III: Detailed Analysis and Tested Vehicle Characteristics, FAA-RD-75-123,III, June 1976.

7. Hanke, D., K. Wilhelm, and H. H. Lange, "Handling Qualities Aspects of CTOL Aircraft with Advanced Flight Controls," Criteria for Handling Qualities of Military Aircraft, AGARD CP-333, June 1982.

8. Gibson, John C., "Piloted Handling Qualities Design Criteria for High Order Flight Control Systems," Criteria for Handling Qualities of Military Aircraft, AGARD CP-333, June 1982.

9. Hoh, Roger H., David G. Mitchell, Irving L. Ashkenas, et al., Background Information and User's Guide for Proposed Handling Qualities Requirements for Military Rotorcraft, Systems Technology, Inc., TR-1194-3, Dec. 1985.

10. Franklin, James A., Robert C. Innis, Gordon H. Hardy, et al., Design Criteria for Flight Path and Airspeed Control for the Approach and Landing of STOL Aircraft, NASA TP-1911, Mar. 1982.

11. Rumold, Robert C., John M. Lehman, Robert L. Stapleford, et al., A STOL Airworthiness Investigation Using Simulations of Representative STOL Aircraft, NASA TM X-62,498, FAA-RD-75-197, May 1975.

12. Stapleford, Robert L., Robert K. Heffley, Charles S. Hynes, et al., A STOL Airworthiness Investigation Using a Simulation of an Augmentor Wing Transport. Volume I: Summary of Results and Airworthiness Implications, NASA TM X-62,395, FAA-RD-74-179,I, Oct. 1974.

Heffley, Robert K., Robert L. Stapleford, Robert C. Rumold, et al., A STOL Airworthiness Investigation Using a Simulation of an Augmentor Wing Transport. Volume II: Simulator Data and Analysis, NASA TM X-62,396, FAA-RD-74-179,II, Oct. 1974.

13. Stapleford, Robert L., Robert K. Heffley, Robert C. Rumold, et al., A STOL Airworthiness Investigation Using a Simulation of a Deflection Slipstream Transport. Volume I: Summary of Results and Airworthiness Implications, NASA TM X-62,392, FAA-RD-74-143-I, Oct. 1974.

Stapleford, Robert L., Robert K. Heffley, Wayne F. Jewell, et al., A STOL Airworthiness Investigation Using a Simulation of a Deflected Slipstream Transport. Volume II: Simulation Data and Analysis, NASA TM X-62,393, FAA-RD-74-143-II, Oct. 1974.

Heffley, Robert K., Wayne F. Jewell, Robert L. Stapleford, et al., A STOL Airworthiness Investigation Using a Simulation of a Deflected Slipstream Transport. Volume III: Breguet 941S Simulation Model, NASA TM X-62,394, FAA-RD-74-143-III, Oct. 1974.

14. Whyte, Patrick H., An Exploratory Investigation of the STOL Landing Maneuver, NASA CR-3191, Dec. 1979.

15. Franklin, James A., and Robert C. Innis, Flight-Path and Airspeed Control During Approach and Landing for Powered-Lift Aircraft, NASA TN D-7791, Oct. 1974.

16. Gerken, Gary, USAF Flying Qualities Requirements for a STOL Transport, ASD-TR-78-13, May 1979.

17. Citurs, K. D., and J. H. Caton, "An Investigation of Flying Qualities Requirements for a STOL Fighter in Approach and Landing," AIAA Paper No. 85-1807, presented at the AIAA 12th Atmospheric Flight Mechanics Conference, Snowmass, CO, 19-21 Aug. 1985.

18. Stapleford, Robert L., and Irving L. Ashkenas, "Effects of Manual Altitude Control and Other Factors on Short-Period Handling Quality Requirements," J. Aircraft, Vol. 5, No. 1, Jan.-Feb. 1968, pp. 41-48.

19. McRuer, Duane, Irving Ashkenas, and Dunstan Graham, Aircraft Dynamics and Automatic Control, Princeton University Press, Princeton, N.J., 1973.

20. McRuer, Duane, "Progress and Pitfalls in Advanced Flight Control Systems," Advances in Guidance and Control Systems, AGARD CP-321, Jan. 1983, pp. 1-1 -- 1-17.

21. Sarrafian, Shahan K., and Bruce G. Powers, Application of Frequency Domain Handling Qualities Criteria to the Longitudinal Landing Task, NASA TM-86728, Aug. 1985.

22. McRuer, D. T., and E. S. Krendel, Mathematical Models of Human Pilot Behavior, AGARDograph No. 188, Jan. 1974.

23. Craig, S. J., R. F. Ringland, and I. L. Ashkenas, An Analysis of Navy Approach Power Compensator Problems and Requirements, Systems Technology, Inc., TR-197-1, Mar. 1971.

24. Mitchell, David G., Richard J. DiMarco, Roger H. Hoh, et al., Users Guide for Handling Qualities Parameter Program, Systems Technology, Inc., TM-1208-1, 15 Jan. 1985.

25. Lee, Robert E., Jr., Gary R. Kreitner, and Stewart A. Stoddart, Flying Qualities Evaluation of the YC-14 Advanced Medium STOL Transport, AFFTC-TR-77-35, Jan. 1978.

26. Wood, Richard A., Roger O. Hanson, Stephan D. Peterson, et al., Flight Control Systems and Flying Qualities Evaluation of the YC-15 Advanced Medium STOL Transport, AFFTC-TR-76-40, Jan. 1977.

27. Smith, K. L., and C. S. Stewart, "A Survey of Control Law Options for Integrated Flight/Propulsion Control for Fighter STOL Approach," AIAA Paper No. 84-1900CP, presented at the AIAA Guidance and Control Conference, Seattle, Washington, 20-22 Aug. 1984.

28. Anderson, D. C., K. E. Sanders, and J. W. Roberts, "Piloted Simulation Evaluation of Advanced Fighter Integrated Flight/Propulsion STOL Controls," AIAA Paper No. 84-1901CP, presented at the AIAA Guidance and Control Conference, Seattle, Washington, 20-22 Aug. 1984.

29. Drake, Douglas E., Robert A. Berg, Gary L. Teper, et al., A Flight Simulator Study of STOL Transport Lateral Control Characteristics, FAA-RD-70-61, Sept. 1970.

30. Berg, Robert A., W. Allen Shirley, Gary L. Teper, et al., A Flight Simulator Study of STOL Transport Directional Control Characteristics, FAA-RD-71-81, June 1971.

31. Smith, R. E., J. V. Lebacqz, and R. C. Radford, Flight Investigation of Lateral-Directional Flying Qualities and Control Power Requirements for STOL Landing Approach Using the X-22A Aircraft. Volume I: Technical Results, Calspan Report AK-5130-F-1 (Volume I), Feb. 1974.

32. Military Specification -- Flying Qualities of Piloted Airplanes, MIL-F-8785C, Nov. 1980.

33. Military Specification -- Flying Qualities of Piloted V/STOL Aircraft, MIL-F-83300, Dec. 1970.

34. Chalk, Charles R., Dante A. DiFranco, J. Victor Lebacqz, et al., Revisions to MIL-F-8785B (ASG) Proposed by Cornell Aeronautical Laboratory Under Contract F33615-71-C1254, AFFDL-TR-72-41, Apr. 1973.

35. Anon., Methods of Analysis and Synthesis of Piloted Aircraft Flight Control Systems, BuAer Report AE-61-4-I, Mar. 1952.

36. Ashkenas, I. L., and S. J. Craig, "Multiloop Piloting Aspects of Longitudinal Approach Path Control," ICAS Paper No. 72-46, presented at the 8th Congress of International Council of the Aeronautical Sciences, Amsterdam, Aug. 28-Sept. 2, 1972.

37. Mitchell, D. G., and R. H. Hoh, "Low Order Approaches to High-Order Systems: Problems and Promises," Journal of Guidance, Control and Dynamics, Vol. 5, No. 5, Sept-Oct 1982 pp. 482-489.

APPENDIX A

LAMARS SIMULATION OF FIGHTER STOL LANDINGS

A. DESCRIPTION OF SIMULATION AND TESTED CONFIGURATIONS

A moving-base piloted simulation of fighter STOL landings was conducted by AFWAL/FIGC on the LAMARS simulator in direct support of this program. Configurations A1L through A6H and R2L through R08M from Table B-2 (Appendix B) were tested. The actual configurations differed slightly from those listed in Table B-2, but the differences are insignificant in terms of obtaining the desired systematic variations in the key handling qualities parameters. The parameters varied in the simulation were pitch attitude bandwidth, ω_{BW_θ}, and flight path lag, $(1/T_{\theta_2})_{eff}$, for rate command/attitude hold (RCAH) and attitude command/attitude hold (ACAH) response-types. Pitch rate overshoot was also varied for the RCAH response-types. The simulation math model consisted of attitude, flight path, and airspeed transfer functions. This type of model is ideally suited for making systematic variations as long as airspeed does not vary significantly.

The simulator cockpit was configured as a typical fighter aircraft with the head-up display illustrated in Figure A-1. The piloting task was to intercept the final approach course from the initial condition illustrated in Figure A-2 and to land in a designated area.

The runway was visible throughout the run and the pilots had raw localizer and glideslope guidance available on the HUD. The velocity vector symbol on the HUD was of particular value as it provided a direct measure of the longitudinal flight path angle. The pilot technique, in most cases, was to superimpose the velocity vector symbol on or near the desired touchdown point. The flight path dynamics in response to control inputs and to attitude changes were therefore immediately obvious to the pilot. This feature was particularly important in terms of simulation fidelity since flight path information is difficult to detect in

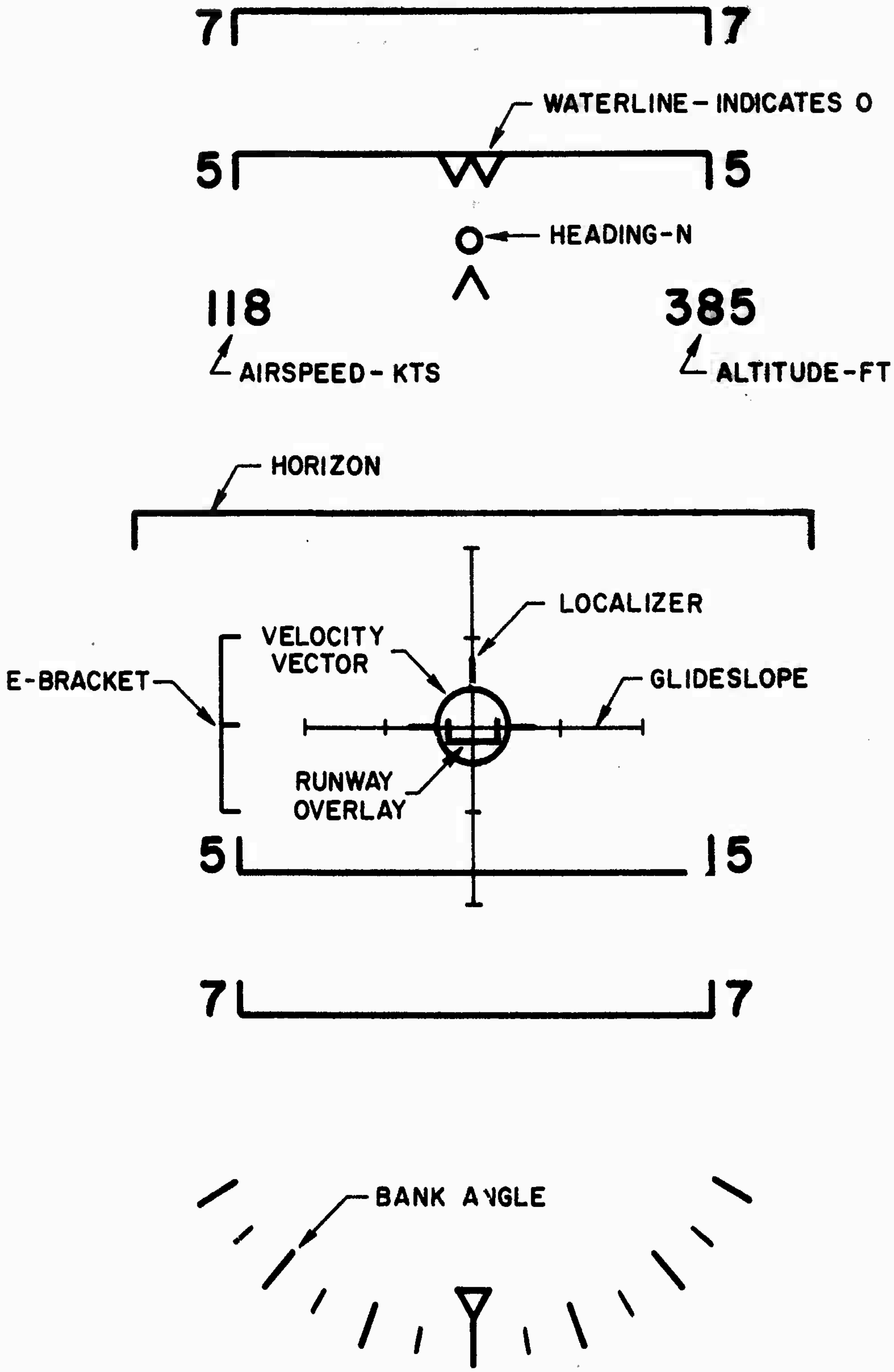


Figure A-1. Baseline Head-up Display (HUD) Configuration ground based simulator visual systems. The touchdown performance parameters required a slight flare maneuver involving a tradeoff between sink rate and dispersion from the desired touchdown point.

Tolerances used to define desired and adequate performance when assigning the Cooper-Harper pilot ratings are defined in Table A-1.

Atmospheric disturbances consisted of a 15 kt crosswind shear to 0 kt in 200 ft of altitude in light random turbulence.

The pilots were allowed as much training as they felt was necessary (typically 1 hr) and were required to accomplish at least four runs before assigning a handling quality rating (HQR) for each tested configuration.

A total of 23 configurations were tested. The transfer functions for these configurations are given in Table A-2 and the values of ω_{BW_θ}, ω_{BW_γ}, and $(1/T_{\theta_2})_{eff}$ are given in Table A-3 along with a summary of the Cooper-Harper pilot ratings. The angle of attack time

Figure A-2. Landing Task Scenario

TABLE A-1. DEFINITION OF DESIRED AND ADEQUATE PERFORMANCE

PERFORMANCE PARAMETER	DESIRED	ADEQUATE
Landing speed	±2 kts	±4 kts
Touchdown sink rate	< 10 ft/sec	< 13 ft/sec
Distance from touchdown point	±75 ft	+150 ft and -100 ft
Lateral touchdown dispersion	±8 ft	±16 ft

TABLE A-2. TRANSFER FUNCTIONS OF TESTED CONFIGURATIONS

CASE	θ/δ_{es}
1AC	$\frac{6.60(0.19)(0.21)}{(3.072)(1.039)[0.989;0.205]}$
2AC	$\frac{2.8(0.19)(0.21)}{(1.690)(1.116)[0.981;0.209]}$
9AC	$\frac{7.3(0.09)(0.56)}{(0.09162)(0.6159)(1.070)(3.089)}$
10AC	$\frac{3.36(0.09)(0.56)}{(0.09247)(0.6578)(1.278)(1.587)}$
17AC	$\frac{8.0(0.06)(1.00)}{(0.06065)(0.9467)(1.652)(2.557)}$
18AC	$\frac{3.50(0.06)(1.00)}{(0.06104)(0.9424)[0.833;1.628]}$
20AC	$\frac{0.79(0.06)(1.00)}{(0.0635)(0.935)[0.541;0.894]}$
1	$\frac{6.60(0.20)(0.20)(0.80)}{(0)(4.061)(1.405)[0.911;0.192]}$
2	$\frac{3.10(0.1744)(0.2260)(1.70)}{(0)(4.061)(1.405)[0.911;0.192]}$
3	$\frac{2.18(0.20)(0.20)(2.40)}{(0)(4.061)(1.405)[0.911;0.192]}$
4	$\frac{1.42(0.1831)(0.2169)(3.70)}{(0)(4.061)(1.405)[0.911;0.192}$
9	$\frac{6.12(0.0907)(0.5371)(0.8622)}{(0)(0.0921)(0.4766)(1.475)(3.767)}$
10	$\frac{3.25(0.09162)(0.5444)(1.604)}{(0)(0.09721)(0.4766)(1.475)(3.767)}$
11	$\frac{2.60(0.08995)(0.5504)(2.00)}{(0)(0.09721)(0.4766)(1.475)(3.767)}$
12	$\frac{1.48(0.0898)(0.5504)(3.50)}{(0)(0.09721)(0.4766)(1.475)(3.767)}$

$$\frac{1}{T_\gamma} = (0.02)$$

$$[\zeta_p;\ \omega_p] = [0.08;\ 0.10]$$

$$\frac{\alpha}{\delta_{es}} = \frac{\theta}{\delta_{es}} \cdot \frac{\alpha}{\theta} = \frac{\theta}{\delta_{es}} \cdot \frac{[\zeta_p;\ \omega_p]}{(1/T_{\theta_1})(1/T_{\theta_2})}$$

$$\frac{\gamma}{\delta_{es}} = \frac{\theta}{\delta_{es}} \cdot \frac{\gamma}{\theta} = \frac{\theta}{\delta_{es}} \cdot \frac{(1/T_\gamma)}{(1/T_{\theta_1})(1/T_{\theta_2})}$$

$$e^{-0.07s} = \frac{[-0.866;49.5]}{[0.866;49.5]}$$

TABLE A-2. (CONCLUDED)

CASE	θ/δ_{es}
17	$\dfrac{7.00(0.05983)(0.8115)(6.9887)}{(0)(0.06262)(0.8096)(1.324)(4.620)}$
18	$\dfrac{4.25(0.06)(1.00)(1.320)}{(0)(0.06261)(0.8736)(1.908)(2.971)}$
19	$\dfrac{2.52(0.06)(1.00)(2.30)}{(0)(0.06261)(0.8736)(1.908)(2.971)}$
20	$\dfrac{1.82(0.06)(1.00)(3.20)}{(0)(0.6261)(0.8736)(1.908)(2.971)}$
15	$\dfrac{4.64(0.03298)(1.104)(2.993)}{(0)(0.0337)(1.200)[0.648;3.534]}$
21	$\dfrac{7.80(0.090)(0.55)(0.65)}{(0)(0.09593)(0.6152)[0.659;2.090]}$
22	$\dfrac{6.25(0.09)(0.55)(0.80)}{(0)(0.096)(0.6235)[0.794;2.075]}$
23	$\dfrac{5.68(0.09)(0.55)(0.90)}{(0.09613)(0.6485)(1.483)(2.789)}$

Note: $(a) = (s + a)$

$[\zeta;\omega_n] = [s^2 + 2\zeta\omega_n s + \omega_n^2]$

TABLE A-3. VALUES OF HANDLING QUALITIES PARAMETERS TESTED

CONFIG.	RESPONSE-TYPE	ω_{BW_θ} (rad/sec)	$(1/T_{\theta_2})_{eff}$ (1/sec)	ω_{BW_γ} (rad/sec)	COOPER-HARPER PILOT RATINGS					$\frac{q_{peak}}{q_{ss}}$
					B	C	H	L	AVG	
1	RCAH	3.4	0.42	0.44		5	3		4	1.0
2		2.3		0.34			5		5	
3		1.8		0.32			4,4		4	
4		1.2		0.31			4,6		5	
9		3.5	0.70	0.63	3	6	2		3.7	
10		2.3		0.46		5	4,5,6		5	
11		1.8		0.43			6		6	
12		1.2		0.40			7,5		6	
15		3.1	2.9	0.97			2		2	
17		3.4	1.0	0.76	4		3,4		3.7	
18		2.5		0.72	3	2,5,6	1		4.5	
19		1.7		0.57			3		3	
20		1.3		0.53			5		5	
21		1.3	0.70					5	5	2.25
22		1.3						5	5	1.75
23		1.3						4	4	1.35
1AC	ACAH	3.4	0.42	0.42	2				2	1.0
2AC		2.3	0.42	0.42	3				3	
9AC		3.5	0.70	0.70	2	3			2.5	
10AC		2.3	0.70	0.70	3	4			3.5	
17AC		3.4	1.0	1.0	3				3	
18AC		2.5	1.0	1.0	3	4			3.5	
20AC		1.3	1.0	1.0	3				3	

responses to a step longitudinal controller input are given in Figure A-3.

Block diagrams of the RCAH and ACAH stability augmentation systems used in the simulation are given in Figure A-4. Ground rules used to develop the configurations are summarized below.

- $1/T_{\theta_1}$ and $1/T_{\theta_2}$ were chosen to yield the desired $(1/T_{\theta_2})_{eff}$ with $1/T_{\gamma_1}$ = 0.02 1/sec.
- T_E was set to minimize the overshoot (q_{peak}/q_{ss} = 1.0).
- The leading coefficient of the γ/δ_e transfer function, A_γ, was set to yield $\Delta\gamma_{max}/\delta\theta_{ss}$ = 1.0.
- The leading coefficient of the airspeed transfer function, A_u, was set to yield $\Delta u/\Delta\theta_{ss}$ = 1.0 kt/deg.
- The stick gain for the RCAH configurations was adjusted to give q_{ss} = 3.3 deg/sec per inch of stick deflection (gradient was 5 lb/in.).
- The stick gains were adjusted for ACAH so that for a 1 inch deflection, pitch attitude and flight path matched, for the first two-plus seconds, the comparable RCAH configuration.

B. PILOT COMMENTARY AND RATINGS

The raw pilot comments and Cooper-Harper ratings are presented on the following pages. The pilot comment card, shown in Figure A-5, was used to guide the commentary.

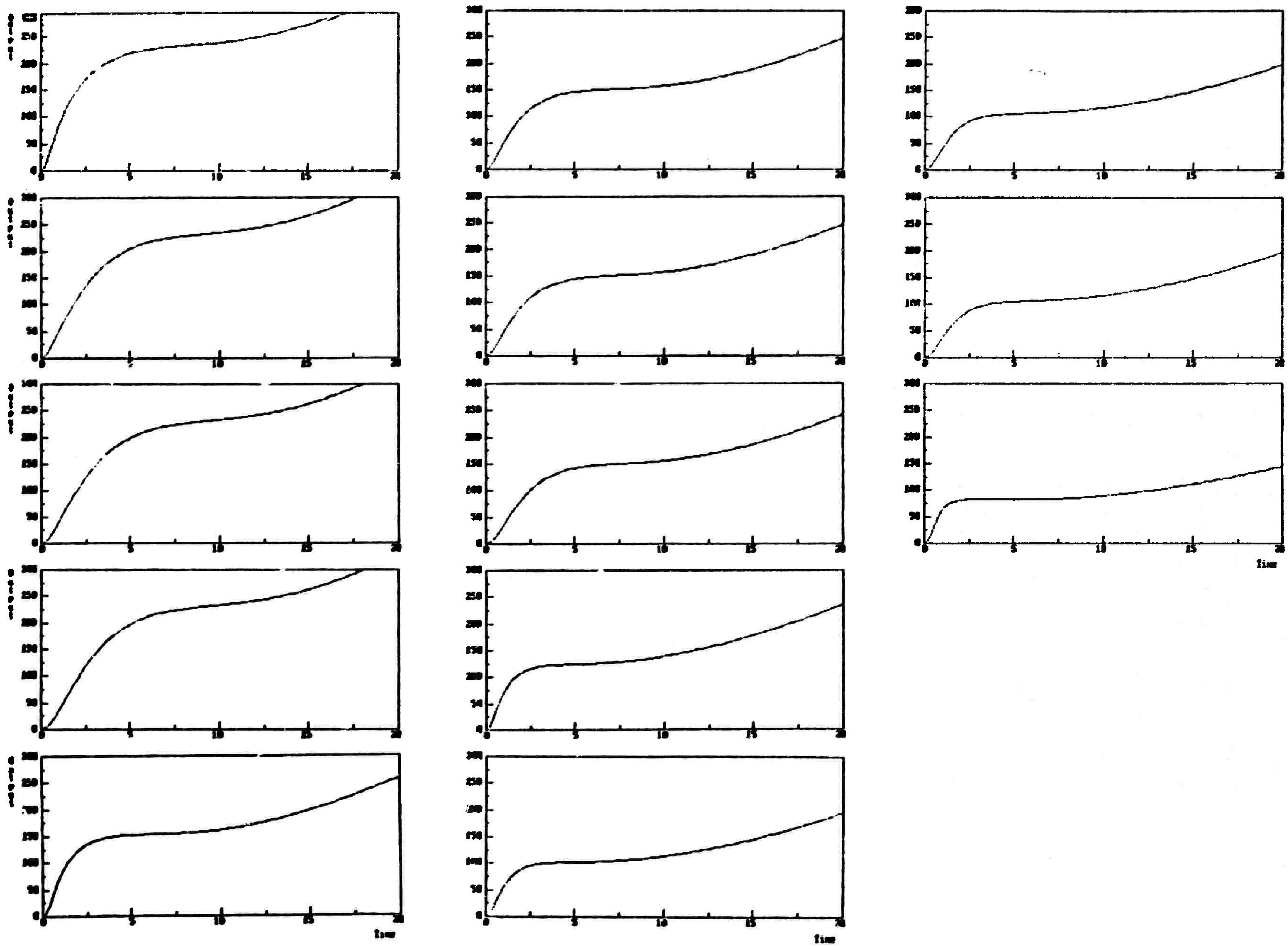
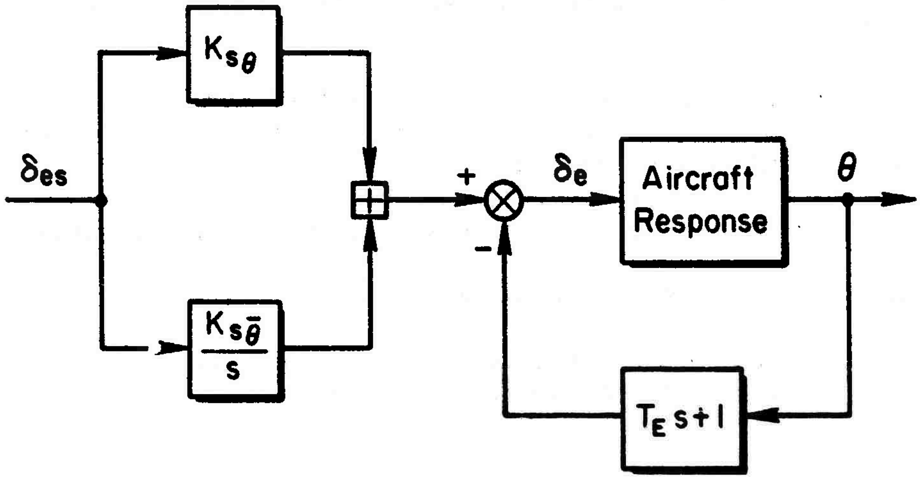
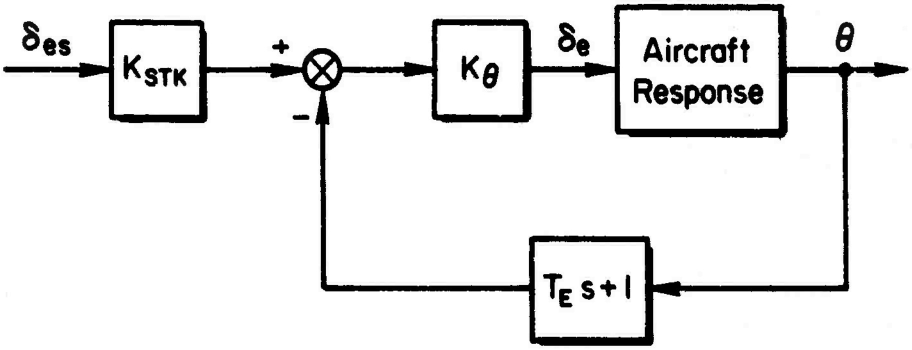


Figure A-3. Angle-of-Attack Responses to Step δ_{es} Input



a) Rate Command/Attitude Hold



b) Attitude Command/Attitude Hold

Figure A-4. Tested Augmentation Systems
(Response-Types)

A. Aircraft Response Characteristics - (rate according to axis/controller)

1. Initial Speed of Responses (sluggish, abrupt)
2. Flight Path Precision (including heading control; predictable, unpredictable, overshoot)
3. Airspeed Control (sluggish, abrupt)
4. Coordination Between Axes/Controllers (OK, overcontrol)

B. Atmospheric Disturbance Characteristics -

1. Effect on Task Performance (none, annoying, distracting)
2. Intensity (light, moderate, severe)
3. Realism

C. Overall Evaluation -

1. Pilot Compensation Required (minimal, moderate, considerable)
2. Special Piloting Techniques Required
3. Performance Obtained (desired, adequate)
4. Cooper-Harper Rating
5. Flying Quality Deficiencies (describe, including level of deficiency)

Figure A-5. Pilot Comment Card Used in Simulation

CONFIGURATION #1

Pilot H (HQR 3)

AIRCRAFT RESPONSE CHARACTERISTICS

If you went to a rapid input the response was a little sluggish, I was not high gain in that task. I could take my time and put it where I wanted to in the low gain situation. I did try once to pull pretty abrupt and it would be sluggish.

Flight path precision was good providing the inputs were slow. Again as I've seen before, as you roll out on final, the flight path marker tends to drop on you with no inputs on the stick.

First time I've seen that when you take power off you start getting a sink rate in the aircraft. If you got airspeed under control the rest of the approach worked out well. As a result, the sluggishness I saw at the fast rate required a little bit greater pitch change to get the kind of flare you needed to get the sink rate down. If you judged the distance ahead you could get desired performance.

ATMOSPHERE

I saw some moderate turbulence occasionally. I don't call that real. I think I should see considerably more light to moderate high frequency stuff with an occasional moderate burst thrown in there.

OVERALL EVALUATION

Pilot compensation was minimal. As long as the task remained low gain I didn't have any problem. I could keep it where I wanted it. I had to keep some small continuous inputs but it seemed real controllable. Overall I could keep the flight path marker where I wanted it. The only problem was the flare, finding a good attitude and a lead point to put it on the mark. That was perhaps the special piloting technique required.

Desired performance obtained.

CONFIGURATION #1

Pilot C (HQR 5)

AIRCRAFT RESPONSE CHARACTERISTICS

The pitch rate is quick, however, the response of the aircraft in angle and flight path is slow.

Aircraft is more sluggish in this configuration.

No trouble with heading control.

In the pitch response there was a tendency to overcontrol. The response was slow and you would put in more than was required.

Airspeed control was normal.

Pitch response was slower than lateral response.

ATMOSPHERE

No problems.

OVERALL EVALUATION

Minimum to moderate compensation required.

Adequate performance obtained, however, not desired yet.

Slow response of the aircraft flight path.

No significant tendency to PIO. Maybe a 1.5 because you can overcontrol sometimes.

CONFIGURATION #2

Pilot H (HQR 5)

AIRCRAFT RESPONSE CHARACTERISTICS

Flight path of aircraft is controllable but seems to be sluggish. Requires a little bit of lead compensation both in the input and output to hold where you want it for a final steady-state value. On the turn to final I have to push considerably to keep the flight path marker tracking across where I want it, that is abnormal.

Airspeed control is fine.

Good coordination between axes.

ATMOSPHERE

Cross wind was good. Turbulence, I didn't notice any of great amount, it wasn't effecting the aircraft very much. Realistically, I thought the winds were good and turbulence was fine.

OVERALL EVALUATION

Pilot compensation required was moderate, due to lead in pitch axis, both required a slightly larger input to get it where you wanted it.

It appeared that if I tried to force my touchdown scatter to be inside adequate or desired, then I could not get my sink rate under control.

Adequate performance.

No tendency to PIO.

CONFIGURATION #3

Pilot H (HQR 4)

AIRCRAFT RESPONSE CHARACTERISTICS

Aircraft response was good. Precision wasn't bad, I think I tended to see turbulence affect my flight path a little bit. It required a lot of small inputs to keep it where I wanted it. It had a tendency to drift off. I could predict both roll and pitch where I wanted to put it.

Airspeed control was not very difficult.

Coordination between axes seemed good, except for the final turn. No tendency to overcontrol.

ATMOSPHERE

Turbulence was annoying. It tended to push the workload up in the pitch axis. Intensity seemed light to moderate, fairly real.

Crosswind seemed light, no factor.

OVERALL EVALUATION

Moderate compensation.

The only special piloting technique was getting a little low in glideslope which tends to give you better control of your rate of descent. Then you can squeek out the distance by changing pitch. The only problem is you get a little greater fluctuation on touchdown zone, I think she was controllable after a while, once I picked up the right glideslope and got a feel for the change in the pitch. At first it did seem a little squirrelly in the pitch. I could see a good change in attitude, but it wouldn't change my flight path vector very quickly, in terms of abrupt change. I didn't see a one for one between θ and γ, some lag involved there which you would expect. But I could get desired performance.

No PIO.

CONFIGURATION #3

Pilot H (HQR 4)

AIRCRAFT RESPONSE CHARACTERISTICS

Speed of response in pitch was sluggish, in terms of flight path it was really sluggish. The final steady state was somewhat unpredictable. If I didn't watch the flight path marker and concentrated on the landing point on the runway, you could work with it.

Airspeed control was no factor.

I didn't see any bad control harmony at all.

ATMOSPHERE

I didn't really notice turbulence at all.

The cross wind was very light.

OVERALL EVALUATION

Pilot compensation was moderate. The kind of compensation you need is to come in low and not rely on a quick change in flight path to get it on the ground. By the time you're used to what you see on short final, you can tell how an input changes the flight path marker. It takes about 2 or 3 seconds for the flight path marker to settle down on the spot that you want. If you get a little low on final, don't change your pitch very much, set your aim point just short of the landing spot, you should be able to obtain desirable performance and accept a sink rate of 6 or 7.

Desired performance obtained.

Roll was good.

No PIO.

CONFIGURATION #4

Pilot H (HQR 4)

Very unpredictable flight path, you can put it there but it will wander on its own. I'm pushing over with considerable force at times, even on final.

AIRCRAFT RESPONSE CHARACTERISTICS

Initial response is not bad. Heading control is good and predictable. Glideslope is somewhat unpredictable, I'll need to make small inputs about my final value in order to keep it there.

Airspeed control was more difficult.

The only coordination problem between axes was a little burbling of the flight path if I made quick pitch movements close into the runway. I could see it bobble on me a little bit through the flight path marker. It did not effect the task and my ability to place it.

ATMOSPHERE

I didn't notice any turbulence at all. Crosswinds were fine, probably a light intensity.

OVERALL EVALUATION

Compensation required was moderate to get desired performance. Again, there was a trade off between touchdown zone and sink rate. It was difficult to get both parameters down well below the desired tolerance, but you could get them in there.

Once I set the flight path marker, it wanted to drop without any inputs when I rolled out so I would have to compensate a little bit. When I would make an input, it would tend to drift in the initial direction of the input after it stops, which means I had to put some small inputs in to keep it there.

Desired performance.

No tendency to PIO.

CONFIGURATION #4

Pilot H (HQR) 6)

AIRCRAFT RESPONSE CHARACTERISTICS

Attitude response was good. Flight path response was really poor, very sluggish.

Very predictable.

Roll was good, heading control was no problem. Speed of response in pitch was good, but the rate of change of flight path was poor.

Airspeed control was harder.

This configuration is very susceptible to develop sink rate when you drop power off. No disharmony between axes.

ATMOSPHERE

I really didn't notice any disturbance and the crosswinds weren't noticeable in flight.

OVERALL EVALUATION

Open loop control in pitch, you have to use your attitude as a way to control your flight path vector rather than using your flight path vector or staring at a point on the ground.

To hit desired performance consistently you have to come in on a low short final and make a very small pitch change on final so that you would see the resultant change about flare time.

Get power stabilized early and on speed because that does effect the sink rate considerably in this configuration. Changes on final are hard to make when you're in close.

No PIO.

Continuing to put in small inputs to keep flight path marker where I want it.

CONFIGURATION #9

Pilot H (HQR 2)

AIRCRAFT RESPONSE CHARACTERISTICS

I'd like a little more response in roll, but other than that, good controllability. No tendency to PIO.

Initial speed of response is a little slow in roll, but as I said, very minor. Pitch very good, flight path precision is excellent. Predictability in both axes is very good. No tendency to overshoot.

Airspeed control, no sweat. You can almost set the power and she stays right in there.

Good coordination between axes. I didn't see any cross harmony problems. No tendency to overcontrol.

ATMOSPHERE

I picked up the atmosphere a little more, I don't know if that's because I had more time to concentrate on what it was doing to me, because she flew so much better. It wasn't annoying and seemed pretty good as far as an overall disturbance. The crosswind intensity did not seem nearly as severe, seemed much easier to control, perhaps it's because I had less concentration on the pitch axis.

OVERALL EVALUATION

Very minimal pilot compensation required. No special piloting techniques. Desired performance could be obtained, just slightly sluggish on the roll in initial response.

CONFIGURATION #9

Pilot C (HQR 6)

All the responses are slow and sluggish. Very hard to predict your flight path or heading control because it's overshooting and out-of-sync. Responses a lot slower than I want to go, so I put an input in, wait, it's not enough so you put in some more, then it starts moving and you have an overshoot situation. Airspeed is easy to control. The longitudinal axis is slow and heading control is slower than I want. However, the lateral axis is quicker than the longitudinal axis.

The crosswind makes it more difficult to make the final landing. As far as coming down the slope, it's no sweat. Once I get down and ready to land and try to align heading, I have a little bit of a problem with it, and it seems difficult for me to land on centerline and heading down the runway. The crosswind was a bit more than annoying and distracting.

Realism wise it's not really realistic, because it's not buffeting much and it's continuous, which you very seldom see.

Overall, I had to use moderate compensation. I had to stay with the flight path marker all the time and couldn't get away from paying attention to it. I had to play a little gamesmanship and get myself out-of-sync with the longitudinal axis to get it to stop where I wanted it to. Always going back and forth. Majority of the problem is with the longitudinal axis.

CONFIGURATION #9

Pilot B (HQR 3)

A little bit sluggish in pitch. Heading control was predictable. Coordination between axes was no problem. The atmosphere was OK. Minimal compensation required.

CONFIGURATION #10

Pilot H (HQR 4)

Minor but annoying deficiency, it's probably in pitch. It appears there is a tendency for the nose to float off if I try to set it with the flight path marker. I guess it will require a little compensation in the opposite direction, kind of annoying. You can't really place the nose and leave it there. You can get desired performance, but it requires moderate pilot compensation.

I didn't see a lot of tight control on my part. So I'd say right now there isn't any tendency for the pilot to produce an undesirable motion, so it would be a 1 on a PIO scale.

AIRCRAFT RESPONSE CHARACTERISTICS

I think the initial speed of response in both axes is good. Flight path precision is not as good. I think you can hold the heading well, it is predictable. I think the flight path is slightly unpredictable, as I mentioned before, a tendency to overshoot.

Airspeed control wasn't a factor at all. It was good.

As far as control harmony, coordination between axes wasn't too bad. It's kind of awkward having to push over in the turn. I guess I'm used to more of a pitch change due to power reduction than what I would see here.

ATMOSPHERE

The crosswind is at the annoying level. I would say that the turbulence isn't a factor at all. Intensity is light to less than light. The crosswinds are realistic, it's an excellent task in that sense.

OVERALL EVALUATION

Pilot compensation is minimal to moderate, I would say moderate from the viewpoint of trying to rate a CHR 4.

I used my flight path marker as a trend indicator, in other words when I got through with trying to position the aircraft visually I'd go back and try to see where it was tracking. It tended to float off. If I concentrated on it, it would drag me off the task.

Both desired and adequate performance was obtained.

CONFIGURATION #10

Pilot H (HQR 5)

AIRCRAFT RESPONSE CHARACTERISTICS

Initial speed of response was good in roll, maybe a little sluggish. Pretty good in pitch. Lags a little in flight path. Still sluggish in flight path control, somewhat predictable.

No tendency to overshoot.

Airspeed control was good.

Coordination between axes was good.

ATMOSPHERE

I could feel the turbulence a little more on this one. Crosswinds were no factor.

OVERALL EVALUATION

You could affect it on short final a little more. The spot where you went open loop was a little closer in to the landing spot.

CONFIGURATION #10

Pilot H (HQR 6)

AIRCRAFT RESPONSE CHARACTERISTICS

Initial response seemed good in both axes, maybe a little sluggish in pitch.

Flight path position and heading control was good. It was predictable.

The flight marker was sluggish and somewhat unpredictable. Difficult to hold when I'm in close.

Good coordination between axes.

ATMOSPHERE

I felt the turbulence a little. Crosswind not a factor with the flight path marker.

OVERALL EVALUATION

Adequate performance requires extensive pilot compensation.

Response was not good on short final, even if I tried to game it a little.

Too much compensation required to really make it work.

Unpredictable in flight path.

CONFIGURATION #10

Pilot C (HQR 5)

Initial pitch response is sluggish. Flight path precision was difficult. There was a slight tendency for a slow PIO.

Airspeed control was normal.

Heading control was good. Very easy to roll out and correct to a heading.

Coordination between axes was not good because there is better response in lateral than pitch. Coupling would be a problem.

ATMOSPHERE

Caused no problem.

OVERALL EVALUATION

Pilot compensation required was moderated for flight path, I was chasing it all the way down final.

Performance was adequate.

CONFIGURATION #11

Pilot H (HQR 6)

Because the aircraft was so sensitive to gust, it makes it very hard. You have to be in the loop a lot to keep your flight path marker where you want it. But then when you get down to flare you are at the mercy of the gust. You almost have to go out of loop and accept a higher sink rate if you want to drop into adequate performance.

The aircraft seemed to respond OK in roll, maybe slightly slow. The pitch was pretty good. I guess in terms of flight path control it was slightly sluggish. Flight path precision was controllable, it was predictable, slight tendency to be sluggish. No tendency to overshoot unless you really tried to stay on top of it.

Airspeed control was a little more difficult, required about twice as much throttle movement to keep myself within 2 Kts.

Coordination between axes, no problem. It was good, no tendency to overcontrol.

ATMOSPHERE

Became annoying, almost distracting. In this case it appeared to have a greater intensity, somewhere between light and moderate on the turbulence, I'd say light. It caused the task workload to go up considerably because the aircraft would be responding so much to the gust. Fairly real.

OVERALL EVALUATION

Considerable pilot compensation was required in pitch axis.

I mentioned because you had the initial response in pitch the flight path motion was maybe slightly sluggish. When you got in on short final you were at the mercy of the gusts, you had to set a sink rate and accept the fact that you would get adequate tolerance. If you got on the stick at all, you would be short or long. Outside that, I think you can get adequate performance although I didn't demonstrate that consistently.

Slightly sluggish, but aircraft response to gust disturbances is pretty bad, makes the task difficult close in, to set a proper flight path.

CONFIGURATION #12

Pilot H (HQR 7)

AIRCRAFT RESPONSE CHARACTERISTICS

Controllability not a question, there is no tendency for PIO.

Roll is the same as before, good response, no tendency to overshoot.

You definitely have a pitch rate system. Flight path lags considerably and there's a tendency you'll overshoot what you want. You try and compensate back, but you overshoot so great, and it lags so much, that by the time you are making an input it's just a guess as to where you are. My best guess is, you could learn to compensate this thing, perhaps. I sure wouldn't want to fly it.

Airspeed control is about the same. Initially, I think because the AOA doesn't change much, the airspeed doesn't change much. They're tied together in terms of coordination. I wanted to say the airspeed was slow to respond, and it was slightly sluggish, but I think that was because we weren't changing the AOA very much.

Coordination between axes, that was fine. I didn't have any tendency to overcontrol in pitch as a result of my bank. Good harmony.

ATMOSPHERE

Seemed like I had a little less cross wind, maybe I was concentrating a lot on my pitch so I didn't see that. Intensity was fine, realism overall was fine.

OVERALL EVALUATION

Definitely considerable. I don't know what kind of technique you would use because of the guess work involved with pitch and flight path lag.

Performance obtained was outside adequate.

CONFIGURATION #12

Pilot H (HQR 5)

AIRCRAFT RESPONSE CHARACTERISTICS

Response was good in both pitch and lateral, maybe a little slow.

Flight path precision was poor and unpredictable.

Followed pitch inputs a little better.

Airspeed was better.

Some real poor coordination in roll and pitch, I got a lot of pitch, out of roll. I don't think it was cross coupling in terms of inputs.*

ATMOSPHERE

I didn't feel much disturbance. Crosswinds seemed to be a little more of a factor, not too bad. Fairly real.

OVERALL EVALUATION

Have a low final, if you have to change your pitch at all in close, you're out of there.

Pulse inputs to try to get in there, but it was just too sluggish to respond.

Power didn't seem to have a great effect. I was trying to stay very close to 130 kts and not require many power changes.

---

*A pure lateral input has no effect on pitch.

CONFIGURATION #15

Pilot H (HQR 6) [Ignored Due to Stick Sensitivity; See Repeat Below]

<u>AIRCRAFT RESPONSE CHARACTERISTICS</u>

Abruptness of response in pitch.

Airspeed control was definitely more difficult.

(Smaller change in power, greater change in airspeed)

Required quite a bit of compensation in pitch. The best thing to do was to leave it alone and once you got the flight path vector aligned to where the landing spot was, just let it come in. If you got in the loop on short final you got a tendency to PIO.

A little lag between pitch attitude and flight path.

CONFIGURATION #15

Pilot H (HQR 2) [Stick gain reduced by 2]

<u>AIRCRAFT RESPONSE CHARACTERISTICS</u>

This is a good aircraft. I think you can get desired performance every time. Just a few negligible deficiencies.

CONFIGURATON #17

Pilot H (HQR 3)

AIRCRAFT RESPONSE CHARACTERISTICS

Good initial response, almost too abrupt. It took a little getting used to. Very precise, you can see that it's almost deadbeat in pitch. Very predictable until you want to make that fine touch for the flare, you could overshoot it without the right touch.

Airspeed control was good. Easy to do.

Appeared to be good control between axes. I did notice on the roll in the flight path marker wants to go up and on roll out it wants to drop.*

ATMOSPHERE

Turbulence was annoying, not really distracting very light intensity. Crosswinds noticeable but not distracting. They seemed real.

OVERALL EVALUATION

Minimal pilot compensation required for desired performance. Compensation is primarily in the type of gain reduction it takes to flare it, you have to give it a small tweek and let it drop in, this decreases you dispersion and increases your sink rate.

Desired performance obtained.

---

*Fixed by decreasing $\Delta\gamma$ to roll gain.

CONFIGURATION #17

Pilot C (HQR 4)

AIRCRAFT RESPONSE CHARACTERISTICS

Pitch response is about normal. Response in lateral axis feels normal also.

Flight path precision is predictable. There is a tendency to overshoot because the pitch axis is more responsive to the stick.

Heading control appears better than the last time, maybe due to better pitch control.

Coordination between axes is pretty close compared to the other ones.

ATMOSPHERE

Crosswind was easily counteracted.

OVERALL EVALUATION

Minimal to moderate pilot compensation required mostly to just hit the spot.

Desired performance obtained.

PIO rating between a 3 and 4.

CONFIGURATION #17

Pilot B (HQR 4)

Pitch was sluggish - roll OK. Overcontrol in pitch. Heading control no problem. Airspeed control good. Atmoshpere was no factor. Moderate compensation required.

CONFIGURATION #18

Pilot H (HQR 1)

AIRCRAFT RESPONSE CHARACTERISTICS

Good response. Good predictability in both roll and pitch, I didn't see any tendency to overshoot. Airspeed was easily controllable. Good coordination between axes.

ATMOSPHERE

Atmosphere was annoying but light intensity, fairly real. Crosswind seems a little light.

OVERALL EVALUATION

No real pilot compensation required. No special technique. Desired performance was obtained. Slightly susceptible to gust in terms of aircraft lift, but I didn't see the flight path marker dancing very much. Good aircraft, nice and stable.

CONFIGURATION #18

Pilot C (HQR 2)

AIRCRAFT RESPONSE CHARACTERISTICS

Initial response in pitch axis, pitch rate are good. Flight path precision is easy. Good pitch configuration.

Heading control noticeably a problem. Heading tended to overshoot. Every time I rolled into or out of a turn, my heading started to wander. Considerable use of rudders and banking required.

Airspeed control was ok.

More control required in the lateral axis than the pitch.

ATMOSHPHERE

Atmosphere was more of a problem, because the crosswind affects lateral control the most.

OVERALL EVALUATION

Moderate amount of pilot compensation required to point the aircraft where I wanted it.

More rudder required.

Desired performance obtained.

No tendency PIO. If it was gusty, I could have had PIO problems because then I would have coupled up in the pitch.

Considering longitudinal axis only, I would rate this a CHR 2.*

*Used CHR 2 since we only care about longitudinal axis.

CONFIGURATION #18

Pilot C (HQR 5)

Once again, the flight path to attitude responses were sluggish. I tended to overcontrol, but not quite as bad as the first time (Configuration 9). There was a tendency to overshoot. Airspeed control was easy. Coordination between axes was about the same as before in that the lateral/directional was a bit slower than I would like but faster than pitch.

The crosswind was more than annoying, in that it complicated the task in the final portion to get lined up and land on the center stripe. Coming down final, I'm spending most of my time getting the flight path marker to stay somewhere on the runway. When I get ready to land I put the flight path marker halfway down the runway and then I spend almost ninety percent of my time trying to make a smooth landing while, at the same time, trying to stay on the center stripe. That is a major task right at the end. This is not very realistic because I don't have any visual cues out the periphery.

Overall, moderate pilot compensation required just to land the airplane, which should not be a factor. The F-15 is the easiest flying airplane in the world and it shouldn't take this much work. No special piloting techniques required other than paying more attention than normal to the landing phase.

Visual Cue Rating Scale Comments:

How bad are the visual cues in the HUD you ask? They are so bad that when I get down to the last hundred feet of the landing phase, I'm watching the altimeter on the HUD to tell where I'm going to be twenty three feet above the ground (altitude at touchdown--terrain board limit). There is very little visual sensation from the display until the last second before you smite the earth. The digital reading on the HUD is the only thing I have to go by. I'd rather have some kind of analog bar to hit a spot (on the bar) rather than a number. Numbers are real hard for me. It takes an extra bit of brain power to figure out what a number means, whereas with an analog bar, I know when the bar hits a certain spot, it's going to be my wheels touching the ground. So I'd rate the visual cues for both the HUD and the simulator visual for sink rate as poor. I'll give you a four.

Almost ninety nine percent of my attitude cue comes from the HUD and its relation to the visual display, so there is a kind of an interaction between the two. It's so hard to chase the flight path marker all the time that I'm not ever paying much attention to aircraft attitude. I'm sure the waterline is just going up and down all the time. I do not fly attitude on the landing phase when I have a flight path marker, at least I don't consciously do it. So, I can't give you a rating on the visual cues in the HUD and the simulator for attitude because I haven't been paying attention to it.

Now, if we're talking about flight path, I'm going strictly by the HUD's positioning of the flight path marker on the visual display. The visual display when I need it the most - in the last fifty feet of landing - is worthless.

CONFIGURATION #18 (repeated)

Pilot C (HQR 6)

No comments on the lateral/directioal axes. The longitudinal axis was sluggish and out-of-sync. This was just like the first two (Configurations 9 and 18). Flight path control was difficult because you overshoot and because there was almost a second delay between the time I made an input to the time I saw something out of the airplane. Airspeed control - no comments.

The crosswind was the same as before, it only complicated the very end.

Moderate pilot compensation. I was spending all of my time worrying about the glideslope and nothing else.

CONFIGURATION #18

Pilot B (HQR 3)

Somewhat sluggish in pitch. Flight path predictable. Good airspeed control. Coordination between axes is OK. Atmosphere OK. Minimal pilot compensation required.

CONFIGURATION #19

Pilot H (HQR 3)

AIRCRAFT RESPONSE CHARACTERISTICS

Response was good, I didn't see any real sluggishness.

Precision was good on both heading control and predictability. Good predictability on the flight path.

Airspeed control was good.

Good coordination between axes. It did have a tendency when I rolled out on final the flight path marker would drop, even though the pitch of the aircraft didn't.

ATMOSPHERE

I really didn't feel much turbulence, an occasional bump, very low frequency. Semi realistic, and had no effect on task performance.

OVERALL EVALUATION

Minimal pilot compensation

Shifting of aim point, I wouldn't say is a special piloting technique. There was a tendency because a lack of peripheral to shift my aim point out just prior to touchdown, which would give me the right kind of pitch up.

Desired performance obtained.

CONFIGURATION #20

Pilot H (HQR 5)

AIRCRAFT RESPONSE CHARACTERISTICS

Requires you go open-loop in the flare.

Speed of response is not bad, I think here we're seeing a much quicker change in flight path for a smaller change in pitch. I'm either overshooting it or undershooting it, if I wait a little bit too long.

Airspeed control seemed slightly sluggish.

Flight path did seem predictable, it required inputs to keep it where I wanted it.

Good coordination between axes.

ATMOSPHERE

Turbulence was annoying. Intensity was light, fairly realistic.

OVERALL EVALUATION

Considerable pilot compensation. Because it was near open-loop. You almost could set an attitude and let it come in. If I went total open-loop I would end up hitting short. If I tried a normal flare I would float down the runway.

Adequate performance obtained.

CONFIGURATION #21

Pilot L (HQR 5)

AIRCRAFT RESPONSE CHARACTERISTICS

It's not as quick as the last one, I wasn't overshooting.

Pitch is slower than last one.

Flight path precision was better. Easier to stay on glidepath until I got in real close.

Airspeed control is fine.

Coordination between axes is still good.

ATMOSPHERE

Compensating for crosswind that dies away.

Intensity is fine.

OVERALL EVALUATION

I really have to compensate a lot to get it in the desired parameters.

Once you get in close enough to see where you're going to touch down it's to late to be putting in any more corrections. It's hard to tell when to flare.

Damping was better longitudinally. You could put it somewhere and it would stay there but, it wasn't quick to move there.

No PIO.

CONFIGURATION #22

Pilot L (HQR 5)

AIRCRAFT RESPONSE CHARACTERISTICS

You need a quick change in your glidepath short in, to get above or below.

Initial speed of response is sluggish, maybe it's just a time delay in there.

I kept overshooting. Once you get in tight I was going above and below glideslope.

Airspeed control was ok.

Coordination between axes is good.

ATMOSPHERE

Intensity is somewhat real, except I don't think crosswind should go away.

OVERALL EVALUATION

I really have to work hard. Because of the crosswind change you have to keep correcting to get on centerline.

Half the problem is being able to see where you are going to hit. In close, the localizer is too sensitive to use.

It's a trade off between hitting the point or landing hard if you're a little high. If you are low you can compensate for that.

I could do better if simulator visual was more realistic.

CONFIGURATION #23

Pilot L (HQR 4)

AIRCRAFT RESPONSE CHARACTERISTICS

I was working hard to compensate.

I would like the rate of response to be a little quicker, I've done this so many times I don't overshoot very bad, but I continue to overshoot. I have to put in a correction and just hold it to see what it's going to do. It's somewhat unpredictable.

Airspeed control is good. Airspeed changes as I would like.

Coordination between axes is good, pitch and roll where fine.

ATMOSPHERE

I've been compensating for a crosswind. I don't know if it's realistic having a straight ramp on the crosswind. Usually from three hundred feet down your crosswind doesn't go away.

OVERALL EVALUATION

Desired performance obtained.

When you try to keep the flight path marker with the glideslope, it's very hard to do. You can push a little bit and it takes a little while for the flight path to go down, you're shooting through your glidepath. If it was just a little quicker, I could catch the glideslope better.

If I worked at it I could get it to PIO.

Configuration #1AC

Pilot B (HQR 2)

Speed of response was very good. Flight path precision - predictable. Airspeed control and coordination between axes were good. Minimal compensation required.

CONFIGURATION #2AC

Pilot B (HQR 3)

Initial speed of response was sluggish in pitch, slowed my inputs down to compensate. Heading control predictable. Airspeed control was OK. Minimal pilot compensation required. Desired performance obtained more frequently.

CONFIGURATION #9AC

Pilot C (HQR 3)

The speed of the responses is a lot more real time and close to what I want, not abrupt and not sluggish. Maybe a little slower than I'd like, but almost right. It's pretty easy to hold flight path now with minimum work on my part. There is a little bit of overshoot and PIO tendency. Airspeed control is good. Coordination between axes seems almost just right.

The atmosphere as not even annoying or distracting. Very easy to compensate for.

There was minimal pilot compensation required. No special piloting techniques.

Visual Cue Rating Scale Comments:

Comments now that would apply to the visual cues, also. The task here (Configuration 9AC) was so much easier than the first two, that I had time to check out visual cues. I realized that before I was so busy trying to keep the flight path marker on the runway that I had no time to look at my peripheral visual cues. This time I had plenty of time to do that. The only correction I had to make was right at the end to land on the stripe and to compensate for the crosswind.

I still need to go to the HUD for altitude before touchdown because I don't get a ground rush or peripheral cues. Some of the other cues are a little better if you have the time to pay attention to them. Once again, the big cue that you need right at the last fifty to one hundred feet before touchdown is not there, and that is a wider field of view for your ground rush and sinking sensation. Sink rate I still rate poor, with a four, because I can't tell I'm sinking with any kind of cue out there until I've sunk a long way.

As far as attitude goes, the only cue I use the visual display for is where to put the flight path marker on the runway to try to gamesmanship the touchdown point. Once again, I don't consciously use attitude in the landing phase. I'm generally an angle-of-attack guy - the F-4 and A-7 are angle-of-attack airplanes. The F-16 is a little bit more of an attitude type landing, but you need the periphery to get that. As far as attitude goes, the visual is poor, a four or a five. The HUD, when it gets down to the landing phase, needs to have a more graduated pitch ladder. I only have a zero and five-degree marks, and the difference of a couple degrees could mean a tail-pipe drag on an F-15 or F-16, so I'd rate the HUD as fair.

CONFIGURATION #9AC

Pilot B (HQR 2)

Hard to get lined up due to crosswind. Minimal to moderate compensation required. Good response in both pitch and roll. Flight path and heading recision - OK. Airspeed control and coordination between axes is OK.

CONFIGURATION #10AC

Pilot C (HQR 4)

Pitch response was sluggish. Flight path precision was predictable but there was a little tendency to overshoot, and that was the undesirable part. This time I was able to evaluate flight path changes with the throttles in that I pulled back on the throttles and started dropping low, which the simulator did almost like a real airplane. No change in coordination between axes.

The crosswind, again, complicated the final portion of the landing, but no other problems.

Minimum to moderate pilot compensation was required just to stop my overshoots and PIO's in the pitch axis. Again, this one was like the last one (Configuration 18AC) in that if I stop making inputs and let the stick go to the original trim position, I could just make small inputs and get where I wanted with just small overshoots. That would be the special piloting technique required.

CONFIGURATION #10AC

Pilot B (HQR 3)

Sluggish response in pitch, PIO when I was abrupt. Airspeed and heading control were good. Moderate compensation required. Requried smoother inputs.

CONFIGURATION #17AC

Pilot B (HQR 3)

Adjustment in pitch - overcontrolled. Initial speed of response and precision - OK. Coordination and airspeed control - OK. No special piloting techniques required.

CONFIGURATION #18AC

Pilot C (HQR 4)

The initial speed of response in the pitch axis was sluggish. Not as bad as the first two (Configuration 9 and 18), not as good as the third (Configuration 9AC), however, sluggish from desired. Flight path precision was hard because of a tendency to lag. When you initially pull the stick back, the flight path marker would go in the opposite direction and I would get out-of-sync with it. The harder I would work at it, the more PIO's I'd get into. If I'd let loose of the stick and stop near where I'd want it, and then make very small changes, it would hold real well. Coordination between axes was the same as before in that the lateral/directional doesn't bother me very much, and the pitch is a little slower.

The atmosphere only complicated the final lining up on the stripe and wasn't any trouble other than that.

Moderate compensation was required until I figured out that if you fly it like a 135, and don't do something, it will probably be alright by itself. Don't fix it if it's not broken type philosophy. Special piloting technique would be the realization that I'm out-of-sync with the flight path and/or my perception of pitch attitude in the landing phase and had to tone down my inputs.

CONFIGURATION #18AC

Pilot B (HQR 3)

Pitch was a little sluggish. The crosswind was difficult right at touchdown. Combination of the two sometimes caused me to be outside performance. Everything else - OK.

CONFIGURATION #20AC

Pilot B (HQR 3)

Initial speed of response sluggish. Roll was excellent. Minimal pilot compensation required. Everything else was good.

APPENDIX B

DOCUMENTATION OF HANDLING QUALITIES CONFIGURATIONS

A. INTRODUCTION

This appendix documents the dynamic characteristics of the longitudinal and lateral-directional configurations discussed in Section V. These configurations provided guidance to the U.S. Air Force for the LAMARS simulation reported in Appendix A, and allowed an analytical investigation of various handling qualities parameters. Documentation is in the form of transfer functions, handling qualities parameters (generated by the computer program described in Reference 26), and time histories.

The aircraft model represents a modern jet fighter (Class IV) design in landing configuration (flaps and gear down) at 130 kts. The aircraft is trimmed on a glideslope angle (γ_0) of 3 deg, and $\alpha_0 = 8.79$ deg. Control is provided by conventional elevator, ailerons, and rudder.

B. LONGITUDINAL CONFIGURATIONS

A total of forty-seven configurations were developed, with variations in response-type, pitch attitude and flight path bandwidths, long-term flight path stability, time delays, and pitch rate overshoot. In addition, several configurations are intended to be evaluated with varying engine lags in order to investigate the tradeoffs between flight path stability and engine response time.

Table B-1 lists the transfer functions for the 47 configurations; Table B-2 lists the values of the key handling qualities parameters discussed in this report, generated by the Reference 26 computer program, and briefly describes the variations in the configurations. A time delay of 0.0125 sec (approximating computational delays) was assumed for all of the configurations.

TABLE B-1. TRANSFER FUNCTIONS FOR LONGITUDINAL CONFIGURATIONS

CONF	Δ	$N_{\delta_{STK}}^{\theta}$	$N_{\delta_{STK}}^{\gamma}$
A1L	(287.0)(353.0)[0.8902, 0.224][0.8037, 0.724]	0.5943(-320.0)(-320.0)[0.8383, 0.213]	-0.0296(0.0126)(-2.283)(2.565)(-320.0)(-320.0)
A3L	(268.1)(371.8)[0.8538, 0.216][0.9619, 1.286]	1.6714(-320.0)(-320.0)[0.8383, 0.213]	-0.0833(0.0126)(-2.283)(2.565)(-320.0)(-320.0)
A6L	(240.9)(398.9)[0.8885, 0.215][0.8638, 2.969]	9.6563(-320.0)(-320.0)[0.7938, 0.211]	-0.4812(0.0103)(-2.257)(2.399)(-320.0)(-320.0)
A1M	(0.0864)(0.7370)(287.0)(353.0)[0.7560, 0.687]	0.5943(0.0911)(0.5650)(-320.0)(-320.0)	-0.0298(0.0165)(-3.308)(3.585)(-320.0)(-320.0)
A3M	(0.0895)(0.6390)(268.1)(371.8)[0.9750, 1.240]	1.6716(0.0911)(0.5650)(-320.0)(-320.0)	-0.0835(0.0165)(-3.308)(3.585)(-320.0)(-320.0)
A6M	(0.0808)(0.7014)(240.9)(398.9)[0.8669, 2.911]	9.6563(0.0922)(0.5613)(-320.0)(-320.0)	-0.4770(0.0169)(-3.369)(3.505)(-320.0)(-320.0)
A10M	(0.0861)(0.6271)(2.402)(8.011)(209.0)(430.0)	18.5699(0.0922)(0.5613)(-320.0)(-320.0)	-0.9255(0.0169)(-3.369)(3.505)(-320.0)(-320.0)
A1H	(0.0775)(0.9744)(287.0)(353.0)[0.7299, 0.706]	0.5943(0.0805)(0.7983)(-320.0)(-320.0)	-0.0296(0.0277)(-3.909)(4.176)(-320.0)(-320.0)
A3H	(0.0795)(1.293)(268.1)(371.8)[0.9642, 1.032]	1.6714(0.0805)(0.7983)(-320.0)(-320.0)	-0.0833(0.0277)(-3.909)(4.176)(-320.0)(-320.0)
A6H	(0.0742)(0.9835)(240.9)(398.9)[0.8682, 2.862]	9.6563(0.0819)(0.7713)(-320.0)(-320.0)	-0.4813(0.0272)(-3.915)(4.040)(-320.0)(-320.0)
A1D1	(0.0864)(0.7380)(24.5)(46.7)[0.7540, 0.719]	0.5943(0.0911)(0.5650)(-35.6)(-35.6)	-0.0298(0.0165)(-3.310)(3.585)(-35.6)(-35.6)
A1D2	(0.0864)(0.7400)(15.3)(33.8)[0.7540, 0.737]	0.5943(0.0911)(0.5650)(-24.6)(-24.6)	-0.0298(0.0165)(-3.308)(3.585)(-24.6)(-24.6)
A1D3	(0.0864)(0.7410)(10.6)(26.9)[0.7530, 0.758]	0.5943(0.0911)(0.5650)(-18.8)(-18.8)	-0.0298(0.0165)(-3.310)(3.585)(-18.8)(-18.8)
A3D1	(0.0895)(0.6350)(1.100)(1.860)(17.5)(53.1)	1.6716(0.0911)(0.5650)(-35.6)(-35.6)	-0.0835(0.0165)(-3.310)(3.585)(-35.6)(-35.6)
A3D2	(0.0895)(0.6330)(1.040)(2.550)(8.730)(39.3)	1.6716(0.0911)(0.5650)(-24.6)(-24.6)	-0.0835(0.0165)(-3.310)(3.585)(-24.6)(-24.6)
A3D3	(0.0895)(0.6310)(1.003)(31.7)[0.8910, 4.100]	1.6716(0.0911)(0.5650)(-18.8)(-18.8)	-0.0835(0.0165)(-3.310)(3.585)(-18.8)(-18.8)
A6D1	(0.0809)(0.6956)(26.8)(99.7)[0.9102, 3.506]	9.6563(0.0922)(0.5613)(-64.0)(-64.0)	-0.4812(0.0169)(-3.369)(3.505)(-64.0)(-64.0)
A6D2	(0.0809)(0.6902)(3.203)(62.5)[0.7272, 7.150]	9.6563(0.0922)(0.5613)(-35.6)(-35.6)	-0.4812(0.0169)(-3.369)(3.505)(-35.6)(-35.6)
A6D3	(0.0809)(0.6850)(2.742)(47.1)[0.3419, 6.171]	9.6563(0.0922)(0.5613)(-24.6)(-24.6)	-0.4812(0.0169)(-3.369)(3.505)(-24.6)(-24.6)
A10D1	(0.0861)(0.6249)(2.329)(114.4)[0.6397, 16.160]	18.5699(0.0921)(0.5613)(-64.0)(-64.0)	-0.9198(0.0169)(-3.369)(3.505)(-64.0)(-64.0)
A10D2	(0.0861)(0.6236)(2.288)(85.1)[0.3282, 12.755]	18.5699(0.0922)(0.5613)(-43.2)(-43.2)	-0.9253(0.0169)(-3.369)(3.505)(-43.2)(-43.2)
A10D3	(0.0862)(0.6227)(2.268)(73.9)[0.1933, 11.334]	18.5699(0.0922)(0.5613)(-35.6)(-35.6)	-0.9253(0.0169)(-3.369)(3.505)(-35.6)(-35.6)
A6MG1	(0.0427)(0.6908)(240.9)(398.9)[0.8665, 2.918]	9.6563(0.0525)(0.5616)(-320.0)(-320.0)	-0.4812(-.0224)(-3.231)(3.407)(-320.0)(-320.0)
A6MG2	(0.0211)(0.6881)(240.9)(398.9)[0.8662, 2.921]	9.6563(0.0303)(0.5638)(-320.0)(-320.0)	-0.4812(-.0467)(-3.158)(3.358)(-320.0)(-320.0)
A6MG3	(-.0067)(0.6792)(240.9)(398.9)[0.8659, 2.926]	9.6563(0.0022)(0.5620)(-320.0)(-320.0)	-0.4812(-.0814)(-3.046)(3.281)(-320.0)(-320.0)
A6LG3	(240.9)(398.9)[0.9653, 0.155][0.8630, 2.980]	9.6563(-320.0)(-320.0)[0.8248, 0.161]	-0.4810(-.0800)(-1.885)(2.118)(-320.0)(-320.0)
A6HG3	(-.0077)(0.6670)(0.6800)(240.9)(398.9)[0.8660, 2.930]	9.6625(0.0012)[0.9940, 0.612][-.9989,319.970]	-0.3720(-.0796)(0.6020)(3.390)(-4.400)(-113.2)(-902.1)
A6HG4	(0.0028)(0.1580)(0.6670)(240.9)(398.9)[0.8620, 2.990]	9.6610(0.6550)[0.9890, 0.075][-.9990,319.980]	-0.3938(-.3340)(0.4960)(1.750)(-2.050)(-128.7)(-795.0)
R2L	(0.0000)(240.9)(398.9)[0.8841, 0.215][0.8638, 2.969]	1.6127(5.988)(-320.0)(-320.0)[0.7899, 0.211]	-0.0803(0.0102)(-2.249)(2.392)(5.988)(-320.0)(-320.0)
R4L	(0.0000)(1.738)(4.255)(234.8)(404.9)[0.9104, 0.217]	5.0141(1.667)(-320.0)(-320.0)[0.7934, 0.211]	-0.2498(0.0105)(1.667)(-2.257)(2.400)(-320.0)(-320.0)
R5L	(0.0000)(1.355)(6.283)(224.3)(415.1)[0.8985, 0.217]	5.5712(1.667)(-320.0)(-320.0)[0.7934, 0.211]	-0.2776(0.0105)(1.667)(-2.257)(2.400)(-320.0)(-320.0)
R8L	(0.0000)(2.324)(10.6)(197.7)(440.7)[0.8309, 0.213]	8.9139(2.500)(-320.0)(-320.0)[0.7934, 0.211]	-0.4441(0.0105)(-2.257)(2.400)(2.500)(-320.0)(-320.0)
R2M	(0.0000)(0.0808)(0.7014)(240.9)(398.9)[0.8669, 2.911]	1.9312(0.0922)(0.5613)(5.000)(-320.0)(-320.0)	-0.0980(0.0169)(-3.369)(3.505)(5.000)(-320.0)(-320.0)
R4M	(0.0000)(0.0790)(0.7920)(1.536)(4.299)(234.8)(404.9)	5.0139(0.0922)(0.5613)(1.667)(-320.0)(-320.0)	-0.2499(0.0169)(1.667)(-3.369)(3.505)(-320.0)(-320.0)
R5M	(0.0000)(0.0801)(0.8160)(1.147)(6.325)(224.2)(415.2)	5.5710(0.0922)(0.5613)(1.667)(-320.0)(-320.0)	-0.2777(0.0169)(1.667)(-3.369)(3.505)(-320.0)(-320.0)
R8M	(0.0000)(0.0871)(0.6151)(2.288)(10.6)(197.7)(440.7)	8.9139(0.0922)(0.5612)(2.500)(-320.0)(-320.0)	-0.4441(0.0169)(2.500)(-3.368)(3.504)(-320.0)(-320.0)
R2H	(0.0000)(0.0742)(0.9835)(240.9)(398.9)[0.8682, 2.862]	1.6127(0.0819)(0.7713)(5.988)(-320.0)(-320.0)	-0.0803(0.0272)(-3.915)(4.040)(5.988)(-320.0)(-320.0)
R4H	(0.0000)(0.0730)(4.328)(234.8)(404.9)[0.9792, 1.278]	5.0141(0.0819)(0.7713)(1.667)(-320.0)(-320.0)	-0.2498(0.0272)(1.667)(-3.915)(4.040)(-320.0)(-320.0)
R5H	(0.0000)(0.0738)(6.306)(224.3)(415.1)[0.9603, 1.127]	5.5712(0.0819)(0.7713)(1.667)(-320.0)(-320.0)	-0.2776(0.0272)(1.667)(-3.915)(4.040)(-320.0)(-320.0)
R8H	(0.0000)(0.0785)(0.8513)(2.257)(10.6)(197.7)(440.7)	8.9139(0.0819)(0.7713)(2.500)(-320.0)(-320.0)	-0.4441(0.0272)(2.500)(-3.915)(4.040)(-320.0)(-320.0)
R05L	(0.0000)(240.9)(398.9)[0.8880, 0.215][0.8638, 2.969]	12.0709(0.8000)(-320.0)(-320.0)[0.7934, 0.211]	-0.6014(0.0105)(0.8000)(-2.257)(2.400)(-320.0)(-320.0)
R08L	(0.0000)(2.564)(6.718)(215.0)(424.2)[0.8449, 0.213]	18.5688(0.9001)(-320.0)(-320.0)[0.7938, 0.211]	-0.9252(0.0103)(0.9001)(-2.257)(2.399)(-320.0)(-320.0)
R05M	(0.0000)(0.0808)(0.7014)(240.9)(398.9)[0.8669, 2.911]	12.0702(0.0922)(0.5613)(0.8000)(-320.0)(-320.0)	-0.6016(0.0165)(0.8000)(-3.369)(3.505)(-320.0)(-320.0)
R08M	(0.0000)(0.0855)(0.6352)(2.506)(6.733)(215.0)(424.2)	18.5688(0.0922)(0.5612)(0.9001)(-320.0)(-320.0)	-0.9252(0.0169)(0.9001)(-3.368)(3.504)(-320.0)(-320.0)
R5D1	(0.0000)(0.0802)(0.7960)(1.172)(107.5)[0.8859, 14.830]	5.5710(0.0922)(0.5613)(1.667)(-64.0)(-64.0)	-0.2777(0.0169)(1.667)(-3.369)(3.505)(-64.0)(-64.0)
R5D2	(0.0000)(0.0802)(0.7796)(1.191)(68.6)[0.4050, 10.345]	5.5710(0.0922)(0.5613)(1.667)(-35.6)(-35.6)	-0.2777(0.0169)(1.667)(-3.369)(3.505)(-35.6)(-35.6)
R5D3	(0.0000)(0.0803)(0.7656)(1.208)(52.4)[0.1550, 8.193]	5.5710(0.0922)(0.5613)(1.667)(-24.6)(-24.6)	-0.2777(0.0169)(1.667)(-3.369)(3.505)(-24.6)(-24.6)

TABLE B-1. (CONCLUDED)

CONF.	$N^{n_{z_{cr}}}_{\delta_{STK}}$	$N^{\alpha}_{\delta_{STK}}$
A1L	0.0213(-320.0)(-320.0)]0.3124, 0.034][0.2097, 43.020]	0.0296(20.3)(-320.0)(-320.0)]0.1551, 0.203]
A3L	0.0598(-320.0)(-320.0)]0.3124, 0.034]]0.2097, 43.020]	0.0833(20.3)(-320.0)(-320.0)]0.1551, 0.203]
A6L	0.3453(-320.0)(-320.0)[0.2720, 0.035][0.6556, 41.412]	0.4812(20.2)(-320.0)(-320.0)]0.1545, 0.204]
A1M	0.0212(-320.0)(-320.0)[0.4789, 0.026][0.9043, 60.700]	0.0296(20.3)(-320.0)(-320.0)[0.1551, 0.203]
A3M	0.0598(-320.0)(-320.0)]0.4789, 0.026][0.9043, 60.700]	0.0833(20.3)(-320.0)(-320.0)]0.1551, 0.203]
A6M	0.3453(30.1)(121.9)(-320.0)(-320.0)[0.4847, 0.026]	0.4770(20.2)(-320.0)(-320.0)[0.1545, 0.204]
A10M	0.6641(30.1)(121.9)(-320.0)(-320.0)[0.4847, 0.026]	0.9255(20.2)(-320.0)(-320.0)]0.1545, 0.204]
A1H	0.0213(35.4)(142.6)(-320.0)(-320.0)[0.7248, 0.025]	0.0296(20.3)(-320.0)(-320.0)]0.1551, 0.203]
A3H	0.0598(35.4)(142.6)(-320.0)(-320.0)]0.7248, 0.025]	0.0833(20.3)(-320.0)(-320.0)[0.1551, 0.203]
A6H	0.3454(26.2)(187.2)(-320.0)(-320.0)]v.7097, 0.025]	0.4813(20.2)(-320.0)(-320.0)[0.1545, 0.204]
A1B1	0.0212(-35.6)(-35.6)]0.4789, 0.026][0.9043, 60.700]	0.0296(20.3)(-35.6)(-35.6)]0.1551, 0.203]
A1B2	0.0212(-24.6)(-24.6)[0.4789, 0.026]]0.9043, 60.700]	0.0296(20.3)(-24.6)(-24.6)[0.1551, 0.203]
A1B3	0.0212(-18.0)(-18.0)[0.4789, 0.026][0.9043, 60.700]	0.0296(-18.0)(-18.0)(20.3)[0.1551, 0.203]
A3B1	0.0598(-35.6)(-35.6)[0.4789, 0.026][0.9043, 60.700]	0.0833(20.3)(-35.6)(-35.6)[0.1551, 0.203]
A3B2	0.0598(-24.6)(-24.6)[0.4789, 0.026][0.9043, 60.700]	0.0833(20.3)(-24.6)(-24.6)[0.1551, 0.203]
A3B3	0.0598(-18.0)(-18.0)[0.4789, 0.026]]0.9043, 60.700]	0.0833(-18.0)(-18.0)(20.3)]0.1551, 0.203]
A6B1	0.3453(30.1)(-64.0)(-64.0)(121.9)]0.4847, 0.026]	0.4812(20.2)(-64.0)(-64.0)]0.1545, 0.204]
A6B2	0.3453(30.1)(-35.6)(-35.6)(121.9)]0.4847, 0.026]	0.4812(20.2)(-35.6)(-35.6)[0.1545, 0.204]
A6B3	0.3453(-24.6)(-24.6)(30.1)(121.9)]0.4847, 0.026]	0.4812(20.2)(-24.6)(-24.6)[0.1545, 0.204]
A10B1	0.6641(30.1)(-64.0)(-64.0)(121.9)[0.4847, 0.026]	0.9255(20.2)(-64.0)(-64.0)[0.1545, 0.204]
A10B2	0.6641(30.1)(-43.2)(-43.2)(121.9)]0.4847, 0.026]	0.9255(20.2)(-43.2)(-43.2)[0.1545, 0.204]
A10B3	0.6641(30.1)(-35.6)(-35.6)(121.9)]0.4847, 0.026]	0.9255(20.2)(-35.6)(-35.6)[0.1545, 0.204]
A6NG1	0.3454(31.6)(108.4)(-320.0)(-320.0)]-.3375, 0.020]	0.4812(20.2)(-320.0)(-320.0)[0.1545, 0.204]
A6NG2	0.3454(-.0084)(-.0290)(32.6)(101.3)(-320.0)(-320.0)	0.4812(20.2)(-320.0)(-320.0)[0.1545, 0.204]
A6NG3	0.3453(-.0003)(-.0710)(34.6)(90.1)(-320.0)(-320.0)	0.4812(20.2)(-320.0)(-320.0)[0.1545, 0.204]
A6LG3	0.3453(-.0210)(-.0454)(-320.0)(-320.0)]0.4601, 35.840]	0.4811(20.2)(-320.0)(-320.0)]0.1545, 0.204]
A6NG3	24.3600(-.0001)(-.0698)(0.6018)(261.3)(360.7)]0.4064, 7.418]	0.3728(0.5939)(23.1)(-123.7)(-890.0)[0.1233, 0.221]
A6NG4	19.5500(-.0012)(-.2899)(0.5065)]0.5512, 4.283][0.9937,310.600]	0.3938(0.6086)(22.5)(-137.7)(-784.6)[0.1303, 0.218]
R2L	0.0577(5.988)(-320.0)(-320.0)]0.2699, 0.035]]0.6511, 41.280]	0.0803(5.988)(20.2)(-320.0)(-320.0)[0.1545, 0.204]
R4L	0.1793(1.667)(-320.0)(-320.0)]0.2750, 0.035]]0.6559, 41.421]	0.2498(1.667)(20.2)(-320.0)(-320.0)[0.1545, 0.204]
R5L	0.1992(1.667)(-320.0)(-320.0)]0.2750, 0.035][0.6559, 41.421]	0.2776(1.667)(20.2)(-320.0)(-320.0)[0.1545, 0.204]
R8L	0.3188(2.500)(-320.0)(-320.0)[0.2750, 0.035]]0.6559, 41.421]	0.4441(2.500)(20.2)(-320.0)(-320.0)[0.1545, 0.204]
R2M	0.0691(5.000)(30.1)(121.9)(-320.0)(-320.0)[0.4847, 0.026]	0.0963(5.000)(20.2)(-320.0)(-320.0)[0.1545, 0.204]
R4M	0.1793(1.667)(30.1)(121.9)(-320.0)(-320.0)[0.4847, 0.026]	0.2499(1.667)(20.2)(-320.0)(-320.0)[0.1545, 0.204]
R5M	0.1992(1.667)(30.1)(121.9)(-320.0)(-320.0)[0.4847, 0.026]	0.2777(1.667)(20.2)(-320.0)(-320.0)[0.1545, 0.204]
R8M	0.3188(2.500)(30.1)(121.9)(-320.0)(-320.0)]0.4845, 0.026]	0.4441(2.500)(20.2)(-320.0)(-320.0)[0.1545, 0.204]
R2H	0.0577(5.988)(26.2)(187.2)(-320.0)(-320.0)[0.7097, 0.025]	0.0803(5.988)(20.2)(-320.0)(-320.0)]0.1545, 0.204]
R4H	0.1793(1.667)(26.2)(187.2)(-320.0)(-320.0)[0.7097, 0.025]	0.2498(1.667)(20.2)(-320.0)(-320.0)]0.1545, 0.204]
R5H	0.1993(1.667)(26.2)(187.2)(-320.0)(-320.0)]0.7097, 0.025]	0.2776(1.667)(20.2)(-320.0)(-320.0)]0.1545, 0.204]
R8H	0.3188(2.500)(26.2)(187.2)(-320.0)(-320.0)]0.7097, 0.025]	0.4441(2.500)(20.2)(-320.0)(-320.0)]0.1545, 0.204]
R05L	0.4317(0.8000)(-320.0)(-320.0)[0.2750, 0.035]]0.6559, 41.421]	0.6014(0.8000)(20.2)(-320.0)(-320.0)]0.1545, 0.204]
R08L	0.6640(0.9001)(-320.0)(-320.0)]0.2720, 0.035][0.6557, 41.414]	0.9252(0.9001)(20.2)(-320.0)(-320.0)[0.1545, 0.204]
R05M	0.4317(0.8000)(30.1)(121.9)(-320.0)(-320.0)]0.4847, 0.026]	0.6016(0.8000)(20.2)(-320.0)(-320.0)]0.1545, 0.204]
R08M	0.6641(0.9001)(30.1)(121.9)(-320.0)(-320.0)[0.4845, 0.026]	0.9252(0.9001)(20.2)(-320.0)(-320.0)[0.1545, 0.204]
R5B1	0.1992(1.667)(30.1)(-64.0)(-64.0)(121.9)]0.4847, 0.026]	0.2777(1.667)(20.2)(-64.0)(-64.0)[0.1545, 0.204]
R5B2	0.1992(1.667)(30.1)(-35.6)(-35.6)(121.9)]0.4847, 0.026]	0.2777(1.667)(20.2)(-35.6)(-35.6)]0.1545, 0.204]
R5B3	0.1992(1.667)(-24.6)(-24.6)(30.1)(121.9)]0.4847, 0.026]	0.2777(1.667)(20.2)(-24.6)(-24.6)[0.1545, 0.204]

TABLE B-2. HANDLING QUALITIES PARAMETERS FOR LONGITUDINAL CONFIGURATIONS

CONF.	ELEVATOR RESPONSES ω_{BW_θ} (rad/sec)	τ_{p_θ} (sec)	θ_p/θ_1 or q_p/q_1	ω_{BW_γ} (rad/sec)	τ_{p_γ} (sec)	$(\frac{1}{T_{\theta_2}})_{eff}$ (rad/sec)	t_{rev} (sec)	$d\gamma/dV$ (deg/kt)	$\frac{\Delta\gamma_{max}}{\Delta\theta_{ss}}$ (-)	DESCRIPTION
A1L	1.5	0.011	1.0-1.1	0.62	0.44	0.44	∞	-0.031	0.54	ACAH -- Vary Pitch BW; Low Flight Path Lag
A3L	3.0	↓	↓	0.85	0.25	↓	↓	↓	↓	
A6L	6.0	↓	↓	1.67	0.13	↓	↓	↓	↓	
A1M	1.5	↓	↓	0.73	0.36	0.69	↓	-0.050	0.77	Medium
A3M	3.0	↓	↓	1.03	0.23	↓	↓	↓	↓	
A6M	6.0	↓	↓	1.94	0.12	↓	↓	↓	↓	
A10M	10.0	↓	↓	2.28	0.072	↓	↓	↓	↓	
A1H	1.5	↓	↓	0.79	0.33	0.86	↓	-0.082	0.80	High
A3H	3.0	↓	↓	1.12	0.21	↓	↓	↓	↓	
A6H	6.0	↓	↓	2.07	0.12	↓	↓	↓	↓	
A1D1	1.3	0.088	↓	0.72	0.45	0.69	↓	-0.050	0.77	ACAH -- Vary Time Delay, Pitch BW & Flight Path Lag
A1D2	1.3	0.128	↓	0.72	0.51	↓	↓	↓	↓	
A1D3	1.2	0.170	↓	0.72	0.56	↓	↓	↓	↓	
A3D1	2.4	0.092	↓	1.03	0.30	↓	↓	↓	0.76	
A3D2	2.3	0.139	↓	1.03	0.35	↓	↓	↓	↓	
A3D3	2.2	0.190	↓	1.03	0.39	↓	↓	↓	↓	
A6D1	5.1	0.054	↓	1.97	0.16	↓	↓	↓	0.73	
A6D2	4.8	0.108	↓	2.02	0.21	↓	↓	↓	↓	
A6D3	4.6	0.170	↓	2.08	0.31	↓	↓	↓	↓	
A10D1	8.3	0.060	↓	2.31	0.10	↓	↓	↓	0.75	
A10D2	8.1	0.097	↓	2.34	0.12	↓	↓	↓	↓	
A10D3	8.1	0.121	↓	2.36	0.14	↓	↓	↓	↓	
A6MT1	6.0	0.011	↓	1.94	0.12	↓	↓	↓	0.77	Variations in $d\gamma/dV$, Engine Lags:
A6MT2	↓	↓	↓	↓		↓	↓	↓	↓	
A6MT3	↓	↓	↓	↓		↓	↓	↓	↓	
A6MG1	↓	↓	↓	1.93		↓	24.9	0.067	0.62	T_E = 1 sec (T1)
A6MG1T1	↓	↓	↓	↓		↓	↓	↓	↓	2 sec (T2)
A6MG1T2	↓	↓	↓	↓		↓	↓	↓	↓	3 sec (T3)
A6MG1T3	↓	↓	↓	↓		↓	↓	↓	↓	
A6MG2	↓	↓	↓	↓		↓	18.3	0.140	0.50	
A6MG2T1	↓	↓	↓	↓		↓	↓	↓	↓	
A6MG2T2	↓	↓	↓	↓		↓	↓	↓	↓	
A6MG2T3	↓	↓	↓	↓		↓	↓	↓	↓	
A6MG3	↓	↓	↓	↓		↓	14.9	0.244	*	
A6MG3T1	↓	↓	↓	↓		↓	↓	↓	↓	
A6MG3T2	↓	↓	↓	↓		↓	↓	↓	↓	
A6MG3T3	↓	↓	↓	↓		↓	↓	↓	↓	
A6LG3	↓	0.010	↓	1.64	0.13	0.43	12.0	0.240	0.33	
A6HG3	↓	↓	↓	2.22	0.091	0.84	14.0	0.239	*	
A6HG4	↓	↓	↓	2.10	0.10	0.77	5.0	1.00	*	
R2L	2.0	0.015	↓	0.38	0.33	0.44	∞	-0.030	0.54	RCAH -- Vary Pitch BW; Low Flight Path Lag
R4L	4.0	0.010	↓	0.42	0.16	↓	↓	-0.031	↓	
R5L	5.0	↓	0.40	0.15		↓	↓	↓	↓	
R8L	8.0	↓	↓	0.40	0.092	↓	↓	↓	↓	
R2M	2.0	0.015	↓	0.55	0.28	0.69	↓	-0.051	0.84	Medium
R4M	4.0	0.010	↓	0.65	0.16	↓	↓	↓	0.73	
R5M	5.0	↓	↓	0.61	0.13	↓	↓	↓	↓	
R8M	8.0	↓	↓	0.63	0.082	↓	↓	↓	0.75	
R2H	2.0	0.015	↓	0.63	0.29	0.86	↓	-0.081	0.80	High
R4H	4.0	0.010	↓	0.78	0.15	↓	↓	↓	0.77	
R5H	5.0	↓	↓	0.73	0.12	↓	↓	↓	0.80	
R8H	8.0	↓	↓	0.77	0.078	↓	↓	↓	0.82	
RO5L	5.0	↓	2.15	0.74	0.15	0.44	↓	-0.031	0.56	RCAH -- Vary Overshoot at Two Values of ω_{BW_θ}
RO8L	8.0	↓	1.98	0.66	0.088	↓	↓	↓	0.57	
RO5M	5.0	↓	2.12	1.26	0.14	0.69	↓	-0.051	0.82	
RO8M	8.0	↓	1.98	1.27	0.085	↓	↓	↓	0.79	
R5D1	4.6	0.057	1.1	0.61	0.13	↓	↓	↓	0.73	RCAH -- Vary Time Delay
R5D2	4.5	0.120	↓	0.61	0.13	↓	↓	↓	0.72	
R5D3	4.8	0.185	↓	0.61	0.12	↓	↓	↓	0.73	

* $\Delta\theta_{ss}$ = ∞ Due to Unstable Root

A mnemonic system was devised for the longitudinal configurations to aid in identification. Following is a description of this identifier:

SYMBOL	VARIABLE	VALUE OR DEFINITION
A	response-type	ACAH
R		RCAH (Low Pitch Rate Overshoot)
RO		RCAH (High Pitch Rate Overshoot)
1,2,3,4, etc.	Pitch Attitude Bandwidth, ω_{BW_θ}	1 = 1.5 rad/sec
		2 = 2 rad/sec
		3 = 3 rad/sec
		4 = 4 rad/sec
		5 = 5 rad/sec
		6 = 6 rad/sec
		8 = 8 rad/sec
		10 = 10 rad/sec
L, M, H	Flight Path Lag, $(1/T_{\theta_2})_{eff}$	L = Low, 0.43 rad/sec
		M = Medium, 0.69 rad/sec
		H = High, 0.86 rad/sec
D	Added Pure Time Delay	D1 = 0.05 or 0.1 sec
		D2 = 0.08, 0.1, or 0.15 sec
		D3 = 0.15 or 0.2 sec
G	$d\gamma/dV$ Variations	G1 — 0.067 deg/kt
		G2 — 0.140 deg/kt
		G3 — 0.240 deg/kt
		G4 — 1.00 deg/kt

Figure B-1 shows step responses of pitch attitude (for ACAH) or pitch rate (for RCAH) for the basic configurations -- i.e., no added time delay, and $d\gamma/dV < 0$. These responses are common to all configurations with the same pitch attitude bandwidth, regardless of flight path bandwidth; for example, the time history of θ/θ_c for $\omega_{BW_\theta} = 6$ rad/sec represents Configurations A6L, A6M, and A6H. Figure B-2 shows the step response of angle-of-attack for the nominal configurations; in this case, however, the magnitude of the response varies with flight path bandwidth, so the time histories of Figure B-2 are for $(1/T_{\theta_2})_{eff} = 0.69$ rad/sec.

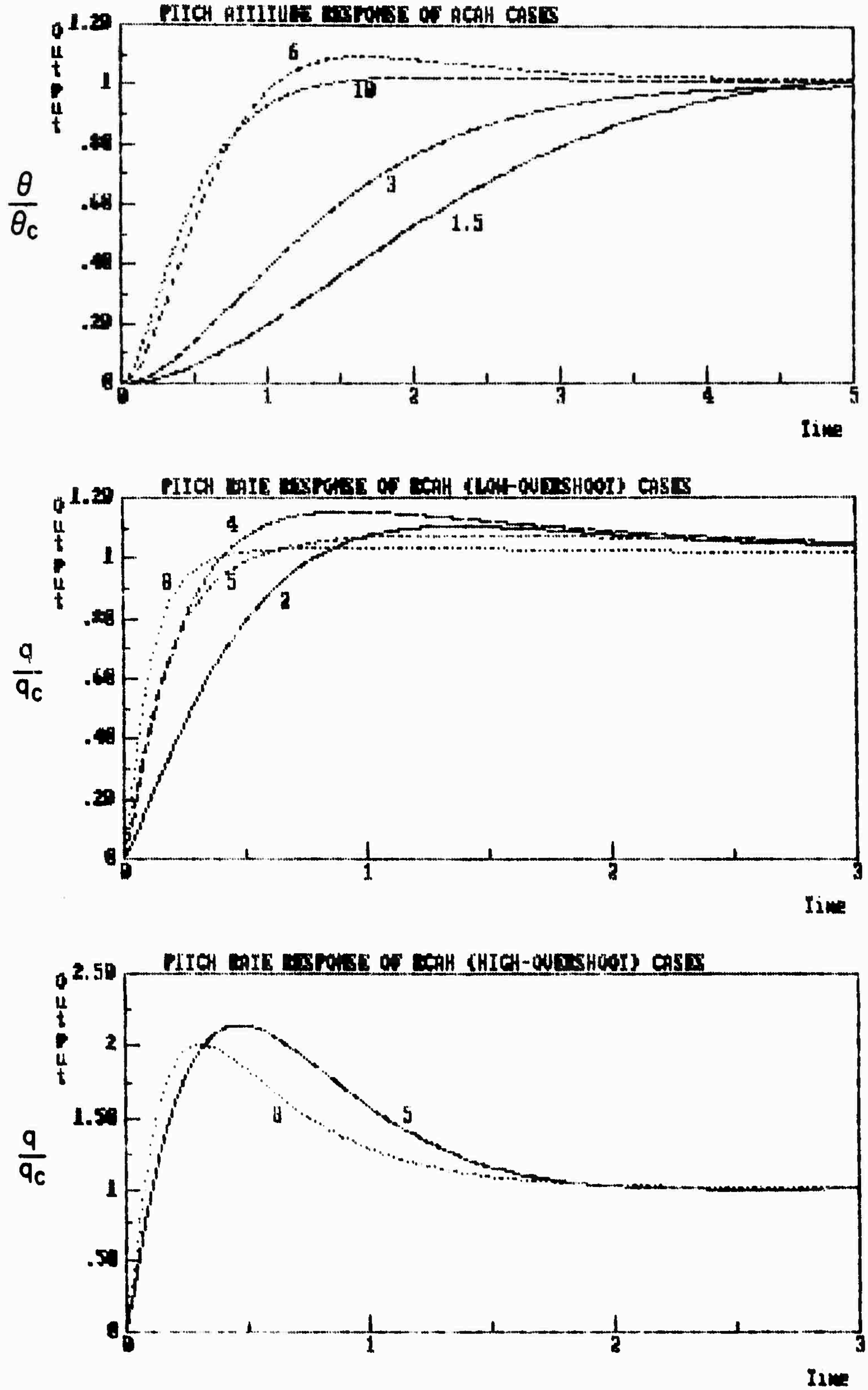
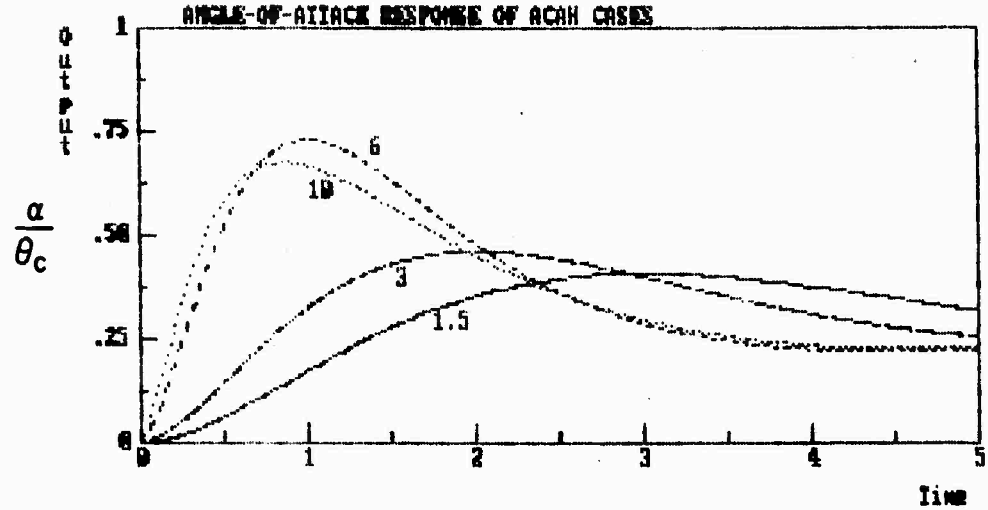


Figure B-1. Time Responses for Basic Configurations (Nominal Time Delay; Step Control Input; Numbers Refer to Pitch Attitude Bandwidth)



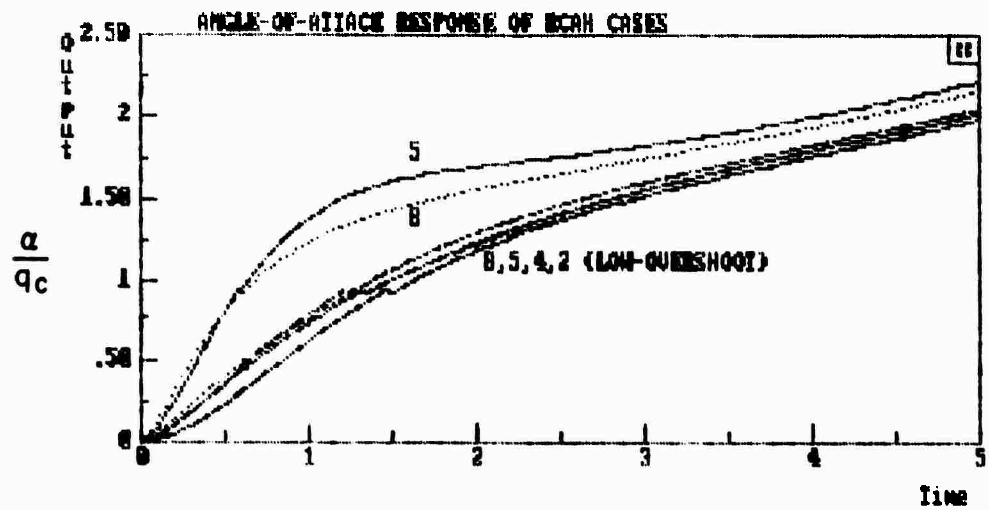


Figure B-2. Step Responses of Angle-of-Attack for Basic Configurations (Nominal Time Delay and $(1/T_{\theta_2})_{eff}$; Numbers Refer to Pitch Attitude Bandwidth)

C. LATERAL-DIRECTIONAL CASES

The eighty-eight lateral-directional variation cases discussed in Section V were developed to explore the generic characteristicstics of various lateral-directional handling qualities criteria. No time delays were used in these cases. Table B-3 lists the pertinent lateral stick and rudder pedal transfer functions, and Table B-4 contains values for the major handling qualities parameters, generated by the Reference 26 program. Table B-4 also documents the key response variations for the cases.

TABLE B-3. TRANSFER FUNCTIONS FOR LATERAL-DIRECTIONAL CASES

CASE	Δ	$N^{\phi}_{\delta_{lat}}$	$N^{\beta}_{\delta_{lat}}$
01	(0.0100)(2.010)[0.164, 1.180]	1.9940[0.183, 1.056]	-.900E-03(0.5120)(1.176)(-122.7)
02	(0.0013)(1.894)[0.103, 0.802]	1.9940[0.127, 0.537]	-.900E-03(-.0327)(1.715)(-123.1)
03	(0.5290)(1.936)[0.299, 0.799]	1.9940[0.535, 0.854]	-.900E-03(-122.2)[0.599, 1.418]
04	(0.0059)(1.930)[0.052, 1.503]	1.9940[0.052, 1.377]	-.900E-03(-.0210)(1.703)(-123.0)
05	(0.0058)(1.957)[0.102, 1.499]	1.9940[0.106, 1.386]	-.900E-03(0.2470)(1.438)(-122.9)
06	(0.0111)(2.000)[0.201, 1.500]	1.9940[0.212, 1.416]	-.900E-03(-122.5)[0.781, 1.093]
07	(0.0929)(1.974)[0.299, 1.499]	1.9940[0.320, 1.459]	-.900E-03(-122.2)[0.591, 1.436]
08	(0.0067)(1.939)[0.051, 2.010]	1.9940[0.052, 1.918]	-.900E-03(0.0661)(1.617)(-123.0)
09	(0.0066)(1.954)[0.102, 2.010]	1.9940[0.103, 1.926]	-.900E-03(0.5550)(1.132)(-122.8)
10	(0.0063)(1.989)[0.201, 2.000]	1.9940[0.202, 1.941]	-.900E-03(-122.3)[0.657, 1.290]
11	(0.0072)(1.944)[0.051, 2.990]	1.9940[0.051, 2.930]	-.900E-03(0.2610)(1.121)(-122.9)
12	(0.0072)(1.949)[0.101, 3.000]	1.9940[0.101, 2.940]	-.900E-03(-122.6)[0.786, 1.075]
13	(0.0071)(1.963)[0.201, 3.000]	1.9940[0.200, 2.950]	-.900E-03(-122.0)[0.515, 1.652]
14	(0.7600)(2.050)[0.396, 0.798]	1.9940[0.635, 0.901]	-.900E-03(-121.9)[0.559, 1.702]
15	(0.2190)(2.040)[0.395, 1.503]	1.9940[0.421, 1.511]	-.900E-03(-121.9)[0.552, 1.723]
16	(0.2270)(2.030)[0.400, 1.992]	1.9940[0.409, 1.988]	-.900E-03(-121.6)[0.507, 1.981]
17	(0.0144)(0.8000)[0.190, 1.137]	1.9940[0.181, 1.056]	-.900E-03(-122.7)[0.337, 0.770]
18	(0.0130)(1.002)[0.181, 1.144]	1.9940[0.181, 1.056]	-.900E-03(-122.7)[0.454, 0.771]
19	(0.0110)(1.500)[0.168, 1.163]	1.9940[0.182, 1.056]	-.900E-03(-122.7)[0.759, 0.773]
20	(0.0091)(3.000)[0.165, 1.199]	1.9940[0.184, 1.057]	-.900E-03(0.2500)(2.440)(-122.7)
21	(0.0000)(0.0000)(0.0100)(1.996)(2.010)(2.016)[0.164, 1.181]	4.4216(0.0000)(0.0588)(1.731)(1.996)[-.709, 0.876]	0.1104(0.0000)(0.0985)(1.996)(1.997)(18.2)[-.548, 0.149]
22	(0.0000)(0.0000)(0.0100)(1.996)(2.010)(2.016)[0.164, 1.181]	2.6245(0.0000)(0.0635)(1.844)(1.995)[-.182, 1.062]	0.0280(0.0000)(0.1453)(1.996)(1.997)(21.3)[-.460, 0.226]
23	(0.0000)(0.0000)(0.0100)(1.996)(2.010)(2.016)[0.164, 1.181]	2.1110(0.0000)(0.0651)(1.943)(1.992)[0.043, 1.140]	0.445E-02(0.0000)(0.1397)(1.995)(1.998)(42.7)[-.372, 0.341]
24	(0.0000)(0.0000)(0.0100)(1.996)(2.010)(2.016)[0.164, 1.181]	1.5450(0.0000)(0.0671)(1.998)(2.226)[0.366, 1.224]	-0.0215(0.0000)(-.3187)(1.996)(1.996)(11.9)[0.625, 0.222]
25	(0.0000)(0.0000)(0.0100)(1.996)(2.010)(2.016)[0.164, 1.181]	0.3136(0.0000)(0.0725)(1.996)(17.2)[0.988, 0.940]	-0.0780(0.0000)(-.2030)(1.996)(1.996)(15.8)[0.512, 0.133]
26	(0.0000)(0.0000)(0.0100)(1.996)(2.010)(2.016)[0.164, 1.181]	-3.2814(0.0000)(1.545)(1.996)(-4.563)[0.950, 0.122]	-0.2428(0.0000)(-.1414)(1.996)(1.997)(16.8)[0.431, 0.088]
27	(0.0000)(0.0000)(0.0100)(1.996)(2.010)(2.016)[0.164, 1.181]	3.1380(0.0000)(-.0670)(0.8986)(-.9042)(2.010)(2.010)	0.0516(0.0000)(1.993)(1.993)(2.010)(19.7)[-.655, 0.047]
28	(0.0000)(0.0000)(0.0100)(1.996)(2.010)(2.016)[0.164, 1.181]	2.6245(0.0000)(0.5787)(2.010)(2.010)[-.738, 0.336]	0.0280(0.0000)(1.987)(1.987)(2.010)(21.8)[-.477, 0.060]
29	(0.0000)(0.0000)(0.0100)(1.996)(2.010)(2.016)[0.164, 1.181]	2.1110(0.0000)(0.1074)(2.011)(2.011)[0.122, 0.860]	0.440E-02(0.0000)(1.961)(1.990)(2.008)(46.1)[-.195, 0.105]
30	(0.0000)(0.0000)(0.0100)(1.996)(2.010)(2.016)[0.164, 1.181]	1.6750(0.0000)(0.0516)(2.010)(2.015)[0.207, 1.406]	-0.0156(0.0000)(0.0837)(-.1630)(1.991)(2.013)(2.050)(8.957)
31	(0.0000)(0.0000)(0.0100)(1.996)(2.010)(2.016)[0.164, 1.181]	1.5450(0.0000)(0.0446)(2.010)(2.017)[0.228, 1.573]	-0.0215(0.0000)(0.0611)(-.1466)(1.991)(2.017)(2.017)(11.2)
32	(0.0000)(0.0000)(0.0100)(1.996)(2.010)(2.016)[0.164, 1.181]	1.0840(0.0000)(0.0300)(2.008)(2.020)[0.314, 2.287]	-0.0426(0.0000)(0.0336)(-.1073)(1.991)(2.007)(2.007)(14.2)
33	(0.0000)(0.0000)(0.0100)(1.996)(2.010)(2.016)[0.164, 1.181]	2.8810(0.0000)(-.0306)(-1.146)(1.322)(1.997)(2.587)	0.0398(0.0000)(1.996)(1.996)(3.900)(20.9)[-.844, 0.037]
34	(0.0000)(0.0000)(0.0100)(1.996)(2.010)(2.016)[0.164, 1.181]	2.3679(0.0000)(-.1301)(-.4999)(0.9762)(1.997)(2.300)	0.0162(0.0000)(1.996)(1.996)(3.811)(26.2)[-.564, 0.052]
35	(0.0000)(0.0000)(0.0100)(1.996)(2.010)(2.016)[0.164, 1.181]	2.1107(0.0000)(0.3363)(1.998)(2.151)[0.105, 0.476]	0.444E-02(0.0000)(1.996)(1.996)(3.669)(49.7)[-.351, 0.074]
36	(0.0000)(0.0000)(0.0100)(1.996)(2.010)(2.016)[0.164, 1.181]	1.7256(0.0000)(0.0470)[0.151, 1.470][1.000, 1.986]	-0.0132(0.0000)(0.0675)(-.1600)(1.995)(1.998)[0.941, 5.551]
37	(0.0000)(0.0000)(0.0100)(1.996)(2.010)(2.016)[0.164, 1.181]	1.6745(0.0000)(0.0422)(1.966)(1.989)[0.141, 1.582]	-0.0156(0.0000)(0.0552)(-.1401)(1.995)(1.998)[0.998, 6.044]
38	(0.0000)(0.0000)(0.0100)(1.996)(2.010)(2.016)[0.164, 1.181]	1.5454(0.0000)(0.0335)(1.922)(1.993)[0.118, 1.866]	-0.0215(0.0000)(0.0389)(-.1158)(1.995)(1.998)(4.512)(10.1)
39	(0.0000)(0.0000)(0.0000)(0.0053)(1.934)(1.976)[0.178, 1.214]	1.9792(0.0000)(0.0000)(0.0272)(1.963)[0.137, 1.214]	-.135E-02(0.0000)(0.0000)(-.0026)(1.645)(1.930)[0.165, 10.374]
40	(0.0000)(0.0000)(0.0000)(0.0053)(1.934)(1.976)[0.178, 1.214]	1.9792(0.0000)(0.0000)(0.0943)(1.960)[0.000, 1.216]	-.135E-02(0.0000)(0.0000)(-.0021)(1.955)(1.930)[0.518, 20.447]
41	(0.0000)(0.0000)(0.0000)(0.0053)(1.934)(1.976)[0.178, 1.214]	1.9792(0.0000)(0.0000)(-.0345)(1.966)[0.260, 1.228]	-.135E-02(0.0000)(0.0000)(-.0016)(1.934)(2.110)(8.094)(-21.9)
42	(0.0000)(0.0000)(0.0000)(0.0053)(1.934)(1.976)[0.178, 1.214]	1.9792(0.0000)(0.0000)(-.1084)(1.971)[0.409, 1.266]	-.135E-02(0.0000)(0.0000)(-.0018)(1.930)(1.996)(11.8)(-47.5)
43	(0.0129)(1.002)[0.181, 1.144]	1.9942[0.181, 1.057]	-.900E-03(-122.8)[0.455, 0.771]
44	(0.0129)(1.002)[0.181, 1.144]	0.8558[0.188, 0.763]	-.900E-03(0.2239)(0.6331)(-122.9)
45	(0.0129)(1.002)[0.181, 1.144]	0.7258[0.200, 0.644]	-.900E-03(0.1192)(0.7555)(-122.9)
46	(0.0129)(1.002)[0.181, 1.144]	0.7158[0.201, 0.632]	-.900E-03(0.1128)(0.7633)(-122.9)
47	(0.0129)(1.002)[0.181, 1.144]	0.6058[0.208, 0.592]	-.900E-03(0.0943)(0.7656)(-122.9)
48	(0.0091)(3.000)[0.165, 1.199]	2.9858[0.184, 1.118]	-.900E-03(0.1657)(2.072)(-122.6)
49	(0.0091)(3.000)[0.165, 1.199]	1.4658[0.185, 0.986]	-.900E-03(0.1553)(2.609)(-122.8)
50	(0.0091)(3.000)[0.165, 1.199]	1.1958[0.187, 0.922]	-.900E-03(0.1087)(2.690)(-122.9)
51	(0.0091)(3.000)[0.165, 1.199]	1.0658[0.199, 0.077]	-.900E-03(0.0682)(2.728)(-122.9)
52	(0.0091)(3.000)[0.165, 1.199]	0.9558[0.192, 0.826]	-.900E-03(0.0713)(2.759)(-122.9)

TABLE B-3. (CONTINUED)

CASE	Δ	$N^{\phi}_{\delta_{lat}}$	$N^{\beta}_{\delta_{lat}}$
21A	(0.0000)(0.0000)(0.0053)(1.934)(1.975)(1.976)[0.170, 1.214]	2.0927(0.0000)(0.0325)(1.933)(2.314)[-.240, 1.107]	0.1104(0.0000)(0.0916)(1.933)(1.986)(18.2)[-.542, 0.114]
22A	(0.0000)(0.0000)(0.0053)(1.934)(1.975)(1.976)[0.170, 1.214]	2.0198(0.0000)(0.0331)(1.932)(2.100)[0.048, 1.172]	0.0280(0.0000)(0.1361)(1.932)(1.985)(21.3)[-.511, 0.172]
23A	(0.0000)(0.0000)(0.0053)(1.934)(1.975)(1.976)[0.170, 1.214]	1.9990(0.0000)(0.0332)(1.930)(2.018)[0.136, 1.199]	0.445E-02(0.0000)(0.1910)(1.927)(1.984)(42.7)[-.490, 0.257]
24A	(0.0000)(0.0000)(0.0053)(1.934)(1.975)(1.976)[0.170, 1.214]	1.9760(0.0000)(0.0334)(1.892)(1.944)[0.236, 1.237]	-0.0215(0.0000)(-.2319)(1.940)(1.988)(11.9)[0.568, 0.200]
25A	(0.0000)(0.0000)(0.0053)(1.934)(1.975)(1.976)[0.170, 1.214]	1.9260(0.0000)(0.0339)(1.540)(1.935)[0.460, 1.383]	-0.0780(0.0000)(-.1408)(1.935)(1.986)(15.7)[0.498, 0.117]
26A	(0.0000)(0.0000)(0.0053)(1.934)(1.975)(1.976)[0.170, 1.214]	1.7801(0.0000)(0.0354)(0.4929)(1.934)[0.679, 2.488]	-0.2428(0.0000)(-.0975)(1.934)(1.986)(16.7)[0.452, 0.078]
27A	(0.0000)(0.0000)(0.0053)(1.934)(1.975)(1.976)[0.170, 1.214]	2.0406(0.0000)(0.1666)(1.923)(1.975)[0.035, 0.537]	0.0516(0.0000)(1.975)(19.7)[-.403, 0.035][1.000, 1.954]
28A	(0.0000)(0.0000)(0.0053)(1.934)(1.975)(1.976)[0.170, 1.214]	2.0198(0.0000)(0.0646)(1.924)(1.975)[0.142, 0.866]	0.0280(0.0000)(1.975)(21.8)[-.304, 0.045][0.999, 1.950]
29A	(0.0000)(0.0000)(0.0053)(1.934)(1.975)(1.976)[0.170, 1.214]	1.9990(0.0000)(0.0397)(1.925)(1.975)[0.171, 1.110]	0.444E-02(0.0000)(1.975)(46.0)[-.153, 0.078][0.998, 1.932]
30A	(0.0000)(0.0000)(0.0053)(1.934)(1.975)(1.976)[0.170, 1.214]	1.9812(0.0000)(0.0299)(1.925)(1.975)[0.188, 1.284]	-0.0156(0.0000)(0.0753)(-.1104)(1.828)(1.975)(2.212)(8.864)
31A	(0.0000)(0.0000)(0.0053)(1.934)(1.975)(1.976)[0.170, 1.214]	1.9760(0.0000)(0.0279)(1.925)(1.975)[0.192, 1.332]	-0.0215(0.0000)(0.0555)(-.0881)(1.854)(1.975)(2.132)(11.2)
32A	(0.0000)(0.0000)(0.0053)(1.934)(1.975)(1.976)[0.170, 1.214]	1.9573(0.0000)(0.0225)(1.926)(1.975)[0.208, 1.492]	-0.0426(0.0000)(0.0318)(-.0622)(1.885)(1.975)(2.059)(14.2)
33A	(0.0000)(0.0000)(0.0053)(1.934)(1.975)(1.976)[0.170, 1.214]	2.0302(0.0000)(-.1647)(-.3083)(1.312)(1.422)(1.936)	0.0398(0.0000)(1.936)(1.986)(3.839)(20.9)[-.513, 0.027]
34A	(0.0000)(0.0000)(0.0053)(1.934)(1.975)(1.976)[0.170, 1.214]	2.0094(0.0000)(0.0986)(1.831)(1.939)[0.285, 0.727]	0.0162(0.0000)(1.937)(1.987)(3.742)(26.2)[-.352, 0.039]
35A	(0.0000)(0.0000)(0.0053)(1.934)(1.975)(1.976)[0.170, 1.214]	1.9990(0.0000)(0.0495)(1.898)(1.946)[0.216, 1.009]	0.444E-02(0.0000)(1.941)(1.988)(3.580)(49.6)[-.234, 0.055]
36A	(0.0000)(0.0000)(0.0053)(1.934)(1.975)(1.976)[0.170, 1.214]	1.9833(0.0000)(0.0287)(1.928)(1.996)[0.170, 1.304]	-0.0132(0.0000)(0.0611)(-.0959)(1.920)(1.982)[0.933, 5.576]
37A	(0.0000)(0.0000)(0.0053)(1.934)(1.975)(1.976)[0.170, 1.214]	1.9812(0.0000)(0.0272)(1.929)(2.004)[0.166, 1.337]	-0.0156(0.0000)(0.0504)(-.0836)(1.924)(1.983)[0.993, 6.051]
38A	(0.0000)(0.0000)(0.0053)(1.934)(1.975)(1.976)[0.170, 1.214]	1.9760(0.0000)(0.0240)(1.930)(2.024)[0.158, 1.418]	-0.0215(0.0000)(0.0363)(-.0677)(1.928)(1.984)(4.521)(10.0)
21B	(0.0000)(0.0000)(0.0668)(1.988)(1.988)(1.996)[0.156, 1.153]	2.0927(0.0000)(0.0946)(-.4756)(1.996)(-2.273)(3.215)	0.1104(0.0000)(0.1055)(1.996)(2.045)(18.2)[-.582, 0.168]
22B	(0.0000)(0.0000)(0.0668)(1.988)(1.988)(1.996)[0.156, 1.153]	2.0198(0.0000)(0.1156)(1.996)(2.569)[-.374, 1.071]	0.0280(0.0000)(0.1568)(1.996)(2.042)(21.3)[-.484, 0.253]
23B	(0.0000)(0.0000)(0.0668)(1.988)(1.988)(1.996)[0.156, 1.153]	1.9990(0.0000)(0.1261)(1.998)(2.206)[-.024, 1.112]	0.445E-02(0.0000)(0.2162)(1.998)(2.035)(42.7)[-.391, 0.382]
24B	(0.0000)(0.0000)(0.0668)(1.988)(1.988)(1.996)[0.156, 1.153]	1.9760(0.0000)(0.1440)(1.404)(1.995)[0.449, 1.313]	-0.0215(0.0000)(-.3929)(1.995)(2.055)(11.9)[0.617, 0.244]
25B	(0.0000)(0.0000)(0.0668)(1.988)(1.988)(1.996)[0.156, 1.153]	1.9260(0.0000)(1.996)[0.846, 0.214][0.603, 2.796]	-0.0780(0.0000)(-.2334)(1.996)(2.048)(15.7)[0.493, 0.144]
26B	(0.0000)(0.0000)(0.0668)(1.988)(1.988)(1.996)[0.156, 1.153]	1.7801(0.0000)(1.996)[0.497, 0.123][0.680, 5.050]	-0.2428(0.0000)(-.1663)(1.996)(2.047)(16.7)[0.403, 0.094]
27B	(0.0000)(0.0000)(0.0668)(1.988)(1.988)(1.996)[0.156, 1.153]	2.0406(0.0000)(-.0442)(1.988)(-2.153)[0.995, 1.886]	0.0516(0.0000)(1.988)(19.7)[-.773, 0.055][1.000, 2.016]
28B	(0.0000)(0.0000)(0.0668)(1.988)(1.988)(1.996)[0.156, 1.153]	2.0198(0.0000)(-.0967)(-1.304)(1.440)(1.884)(1.988)	0.0280(0.0000)(1.988)(21.8)[-.570, 0.071][0.999, 2.013]
29B	(0.0000)(0.0000)(0.0668)(1.988)(1.988)(1.996)[0.156, 1.153]	1.9990(0.0000)(0.4831)(1.933)(1.988)[-.097, 0.608]	0.444E-02(0.0000)(1.988)(46.1)[-.245, 0.123][0.998, 1.998]
30B	(0.0000)(0.0000)(0.0668)(1.988)(1.988)(1.996)[0.156, 1.153]	1.9812(0.0000)(0.0848)(1.949)(1.988)[0.203, 1.452]	-0.0156(0.0000)(0.0932)(-.2235)(1.890)(1.988)(2.254)(8.892)
31B	(0.0000)(0.0000)(0.0668)(1.988)(1.988)(1.996)[0.156, 1.153]	1.9760(0.0000)(0.0672)(1.953)(1.988)[0.215, 1.632]	-0.0215(0.0000)(0.0674)(-.1813)(1.916)(1.988)(2.183)(11.2)
32B	(0.0000)(0.0000)(0.0668)(1.988)(1.988)(1.996)[0.156, 1.153]	1.9573(0.0000)(0.0387)(1.961)(1.988)[0.249, 2.156]	-0.0426(0.0000)(0.0362)(-.1361)(1.948)(1.988)(2.115)(14.2)
33B	(0.0000)(0.0000)(0.0668)(1.988)(1.988)(1.996)[0.156, 1.153]	2.0302(0.0000)(-.0246)(1.996)(-2.433)[0.889, 2.377]	0.0398(0.0000)(1.996)(2.049)(3.868)(20.9)[-.998, 0.043]
34B	(0.0000)(0.0000)(0.0668)(1.988)(1.988)(1.996)[0.156, 1.153]	2.0094(0.0000)(-.0619)(-1.394)(1.995)[0.898, 1.992]	0.0162(0.0000)(1.995)(2.052)(3.775)(26.2)[-.671, 0.061]
35B	(0.0000)(0.0000)(0.0668)(1.988)(1.988)(1.996)[0.156, 1.153]	1.9990(0.0000)(1.995)[-.910, 0.369][0.937, 1.590]	0.444E-02(0.0000)(1.995)(2.058)(3.616)(49.6)[-.424, 0.086]
36B	(0.0000)(0.0000)(0.0668)(1.988)(1.988)(1.996)[0.156, 1.153]	1.9833(0.0000)(0.0727)(2.001)(2.068)[0.140, 1.517]	-0.0132(0.0000)(0.0746)(-.1975)(2.001)(2.022)[0.936, 5.570]
37B	(0.0000)(0.0000)(0.0668)(1.988)(1.988)(1.996)[0.156, 1.153]	1.9812(0.0000)(0.0617)(1.999)(2.111)[0.132, 1.631]	-0.0156(0.0000)(0.0606)(-.1744)(1.999)(2.029)[0.994, 6.051]
38B	(0.0000)(0.0000)(0.0668)(1.988)(1.988)(1.996)[0.156, 1.153]	1.9760(0.0000)(0.0447)(1.997)(2.199)[0.121, 1.881]	-0.0215(0.0000)(0.0421)(-.1462)(1.997)(2.036)(4.529)(10.0)

TABLE B-3. (CONTINUED)

CASE	$N^{\beta}_{\delta_{ped}}$	$N^{r}_{\delta_{lat}}$	$N^{r}_{\delta_{ped}}$
01	0.0263(-.0655)(1.996)(17.2)	-0.1110(-1.769)[0.388, 1.268]	-0.4440(1.930)[-.091, 0.622]
02	0.0263(0.0367)(1.909)(16.9)	-0.1110(-1.333)[0.356, 0.759]	-0.4440(1.963)[-.074, 0.673]
03	0.0263(-.0182)(1.943)(17.8)	-0.1110(-1.549)[0.373, 1.018]	-0.4440(1.950)[-.805, 0.653]
04	0.0263(0.0087)(1.927)(16.9)	-0.1110(-2.030)[0.402, 1.565]	-0.4440(1.896)[-.114, 0.561]
05	0.0263(-.0152)(1.940)(17.1)	-0.1110(-2.030)[0.402, 1.565]	-0.4440(1.896)[-.114, 0.561]
06	0.0263(-.0462)(1.974)(17.4)	-0.1110(-2.040)[0.403, 1.577]	-0.4440(1.894)[-.115, 0.558]
07	0.0263(-.0164)(1.941)(17.0)	-0.1110(-2.060)[0.404, 1.597]	-0.4440(1.892)[-.117, 0.553]
08	0.0263(0.0052)(1.930)(17.0)	-0.1110(-2.430)[0.418, 1.992]	-0.4440(1.819)[-.200, 0.389]
09	0.0263(-.0024)(1.934)(17.2)	-0.1110(-2.430)[0.418, 1.992]	-0.4440(1.819)[-.200, 0.389]
10	0.0263(-.0170)(1.944)(17.6)	-0.1110(-2.430)[0.418, 1.992]	-0.4440(1.819)[-.200, 0.389]
11	0.0263(0.0123)(1.921)(17.0)	-0.1110(-3.090)[0.437, 2.700]	-0.4440(0.5370)(-.7330)(1.567)
12	0.0263(0.0229)(1.907)(17.4)	-0.1110(-3.090)[0.437, 2.700]	-0.4440(0.5370)(-.7330)(1.567)
13	0.0263(0.0437)(1.880)(18.0)	-0.1110(-3.090)[0.437, 2.700]	-0.4440(0.5370)(-.7330)(1.567)
14	0.0263(0.0345)(2.060)(18.1)	-0.1110(-1.536)[0.407, 1.163]	-0.4440(2.110)[-.062, 0.615]
15	0.0263(0.0684)(2.050)(18.1)	-0.1110(-2.000)[0.428, 1.664]	-0.4440(2.060)[-.103, 0.521]
16	0.0263(0.1566)(2.060)(18.4)	-0.1110(-2.310)[0.448, 2.050]	-0.4440(2.090)[-.195, 0.356]
17	0.0263(-.1520)(0.9180)(17.2)	-0.1110(-2.520)[0.271, 1.061]	-0.4440(1.144)[-.305, 0.808]
18	0.0263(-.1285)(1.076)(17.2)	-0.1110(-2.390)[0.285, 1.090]	-0.4440(1.238)[-.261, 0.777]
19	0.0263(-.0893)(1.509)(17.2)	-0.1110(-2.060)[0.328, 1.173]	-0.4440(1.535)[-.165, 0.697]
20	0.0263(-.0415)(2.970)(17.2)	-0.1110(-1.340)[0.533, 1.456]	-0.4440(2.820)[-.010, 0.514]
21	0.0263(0.0000)(0.0000)(-.0656)(1.996)(1.997)(2.010)(17.2)	-1.9908(0.0000)(0.0587)(-.4885)(1.937)(1.996)[0.138, 0.667]	-0.4445(0.0000)(0.0000)(1.931)(1.996)(2.010)[-.091, 0.622]
22	0.0263(0.0000)(0.0000)(-.0656)(1.996)(1.997)(2.010)(17.2)	-0.5991(0.0000)(0.0633)(-1.009)(1.949)(1.995)[0.244, 0.812]	-0.4445(0.0000)(0.0000)(1.931)(1.996)(2.010)[-.092, 0.622]
23	0.0263(0.0000)(0.0000)(-.0656)(1.996)(1.997)(2.010)(17.2)	-0.2013(0.0000)(0.0649)(-1.964)(1.973)(1.992)[0.255, 0.987]	-0.4445(0.0000)(0.0000)(1.931)(1.996)(2.010)[-.092, 0.622]
24	0.0263(0.0000)(0.0000)(-.0656)(1.996)(1.997)(2.010)(17.2)	0.2366(0.0000)(0.0669)(1.412)(1.769)(1.998)[-.168, 1.116]	-0.4445(0.0000)(0.0000)(1.931)(1.996)(2.010)[-.091, 0.622]
25	0.0263(0.0000)(0.0000)(-.0656)(1.996)(1.997)(2.010)(17.2)	1.1905(0.0000)(0.0723)(0.4537)(1.918)(1.996)[-.257, 0.811]	-0.4445(0.0000)(0.0000)(1.931)(1.996)(2.010)[-.092, 0.622]
26	0.0263(0.0000)(0.0000)(-.0656)(1.996)(1.997)(2.010)(17.2)	3.9744(0.0000)(1.927)(1.996)[0.947, 0.118][-.200, 0.677]	-0.4445(0.0000)(0.0000)(1.931)(1.996)(2.010)[-.091, 0.622]
27	0.0263(0.0000)(0.0000)(-.0656)(1.996)(1.997)(2.010)(17.2)	-0.9969(0.0000)(-.0649)(1.646)(2.009)(2.009)[-.035, 0.478]	-0.4445(0.0000)(0.0000)(1.931)(1.996)(2.010)[-.092, 0.622]
28	0.0263(0.0000)(0.0000)(-.0656)(1.996)(1.997)(2.010)(17.2)	-0.5991(0.0000)(-.2186)(1.433)(2.009)(2.009)[0.213, 0.360]	-0.4445(0.0000)(0.0000)(1.931)(1.996)(2.010)[-.092, 0.622]
29	0.0263(0.0000)(0.0000)(0.0656)(1.996)(1.997)(2.010)(17.2)	-0.2012(0.0000)(0.1104)(-1.016)(2.010)(2.010)[0.688, 1.037]	-0.4445(0.0000)(0.0000)(1.931)(1.996)(2.010)[-.092, 0.622]
30	0.0263(0.0000)(0.0000)(-.0656)(1.996)(1.997)(2.010)(17.2)	0.1366(0.0000)(0.0514)(2.009)(2.015)(3.668)[-.031, 0.971]	-0.4445(0.0000)(0.0000)(1.931)(1.996)(2.010)[-.091, 0.622]
31	0.0263(0.0000)(0.0000)(-.0656)(1.996)(1.997)(2.010)(17.2)	0.2366(0.0000)(0.0444)(2.008)(2.017)(2.931)[-.061, 0.897]	-0.4445(0.0000)(0.0000)(1.931)(1.996)(2.010)[-.091, 0.622]
32	0.0263(0.0000)(0.0000)(-.0656)(1.996)(1.997)(2.010)(17.2)	0.5940(0.0000)(0.0300)(2.007)(2.023)(2.317)[-.088, 0.766]	-0.4445(0.0000)(0.0000)(1.931)(1.996)(2.010)[-.091, 0.622]
33	0.0263(0.0000)(0.0000)(-.0656)(1.996)(1.997)(2.010)(17.2)	-0.7978(0.0000)(-.0304)(1.913)(1.997)(3.708)[-.093, 0.534]	-0.4445(0.0000)(0.0000)(1.931)(1.996)(2.010)[-.091, 0.622]
34	0.0263(0.0000)(0.0000)(-.0656)(1.996)(1.997)(2.010)(17.2)	-0.4004(0.0000)(-.1125)(1.887)(1.997)(3.422)[-.038, 0.411]	-0.4445(0.0000)(0.0000)(1.931)(1.996)(2.010)[-.091, 0.622]
35	0.0263(0.0000)(0.0000)(-.0656)(1.996)(1.997)(2.010)(17.2)	-0.2012(0.0000)(-.5550)(1.786)(1.998)(2.884)[0.694, 0.292]	-0.4445(0.0000)(0.0000)(1.931)(1.996)(2.010)[-.091, 0.622]
36	0.0263(0.0000)(0.0000)(-.0656)(1.996)(1.997)(2.010)(17.2)	0.0970(0.0000)(0.0468)(6.498)[-.015, 0.916][1.000, 1.990]	-0.4445(0.0000)(0.0000)(1.931)(1.996)(2.010)[-.091, 0.622]
37	0.0263(0.0000)(0.0000)(-.0656)(1.996)(1.997)(2.010)(17.2)	0.1366(0.0000)(0.0420)(1.986)(1.986)(5.762)[-.032, 0.867]	-0.4445(0.0000)(0.0000)(1.931)(1.996)(2.010)[-.091, 0.622]
38	0.0263(0.0000)(0.0000)(-.0656)(1.996)(1.997)(2.010)(17.2)	0.2366(0.0000)(0.0334)(1.967)(1.993)(5.009)[-.055, 0.795]	-0.4445(0.0000)(0.0000)(1.931)(1.996)(2.010)[-.091, 0.622]
39	0.0263(0.0000)(0.0000)(0.0000)(-.0019)(1.934)(1.934)(17.2)	-.244E-02(0.0000)(0.0000)(0.0265)(1.961)(-172.1)[0.391, 1.010]	-0.4445(0.0000)(0.0000)(0.0000)(1.770)(1.934)[0.119, 0.199]
40	0.0263(0.0000)(0.0000)(0.0000)(-.0019)(1.934)(1.934)(17.2)	-.244E-02(0.0000)(0.0000)(0.1023)(1.958)(-339.9)[0.875, 0.682]	-0.4445(0.0000)(0.0000)(0.0000)(1.770)(1.934)[0.119, 0.199]
41	0.0263(0.0000)(0.0000)(0.0000)(-.0019)(1.934)(1.934)(17.2)	-.244E-02(0.0000)(0.0000)(-.0392)(-1.291)(1.964)[-.659, 10.940]	-0.4445(0.0000)(0.0000)(0.0000)(1.770)(1.934)[0.119, 0.199]
42	0.0263(0.0000)(0.0000)(0.0000)(-.0019)(1.934)(1.934)(17.2)	-.244E-02(0.0000)(0.0000)(1.970)(2.956)(187.7)[-.668, 0.193]	-0.4445(0.0000)(0.0000)(0.0000)(1.770)(1.934)[0.119, 0.199]
43	0.0263(-.1286)(1.076)(17.2)	-0.1110(-2.392)[0.285, 1.091]	-0.4445(1.238)[-.261, 0.777]
44	0.0263(-.1286)(1.076)(17.2)	-0.1110(-.9139)[0.483, 0.834]	-0.4445(1.238)[-.261, 0.777]
45	0.0263(-.1286)(1.076)(17.2)	-0.1110(-.7052)[0.533, 0.737]	-0.4445(1.238)[-.261, 0.777]
46	0.0263(-.1286)(1.076)(17.2)	-0.1110(-.6873)[0.539, 0.728]	-0.4445(1.238)[-.261, 0.777]
47	0.0263(-.1286)(1.076)(17.2)	-0.1110(-.6311)[0.553, 0.696]	-0.4445(1.238)[-.261, 0.777]
48	0.0263(-.0415)(2.971)(17.2)	-0.1110(-2.255)[0.352, 1.455]	-0.4445(2.827)[-.010, 0.514]
49	0.0263(-.0415)(2.971)(17.2)	-0.1110(-.9345)[0.688, 1.396]	-0.4445(2.827)[-.010, 0.514]
50	0.0263(-.0415)(2.971)(17.2)	-0.1110(-.7339)[0.795, 1.329]	-0.4445(2.827)[-.010, 0.514]
51	0.0263(-.0415)(2.971)(17.2)	-0.1110(-.6350)[0.860, 1.282]	-0.4445(2.827)[-.010, 0.514]
52	0.0263(-.0415)(2.971)(17.2)	-0.1110(-.5476)[0.925, 1.231]	-0.4445(2.827)[-.010, 0.514]

TABLE B-3. (CONCLUDED)

CASE	$N^{\beta}_{\delta_{ped}}$	$N^{r}_{\delta_{lat}}$	$N^{r}_{\delta_{ped}}$
21A	0.0263(0.0000)(0.0000)(-.0288)(1.934)(1.975)(1.986)(17.2)	-1.9908(0.0000)(0.0322)(-.5892)(1.933)(2.020)[0.347, 0.599]	-0.4445(0.0000)(0.0000)(1.934)(1.975)(2.024)[-.007, 0.408]
22A	0.0263(0.0000)(0.0000)(-.0288)(1.934)(1.975)(1.986)(17.2)	-0.5991(0.0000)(0.0328)(-1.087)(1.932)(2.012)[0.373, 0.798]	-0.4445(0.0000)(0.0000)(1.934)(1.975)(2.024)[-.007, 0.408]
23A	0.0263(0.0000)(0.0000)(-.0288)(1.934)(1.975)(1.986)(17.2)	-0.2013(0.0000)(0.0330)(1.929)(1.999)(-2.059)[0.331, 1.002]	-0.4445(0.0000)(0.0000)(1.934)(1.975)(2.024)[-.007, 0.408]
24A	0.0263(0.0000)(0.0000)(-.0288)(1.934)(1.975)(1.986)(17.2)	0.2366(0.0000)(0.0332)(1.407)(1.941)(2.125)[-.173, 1.077]	-0.4445(0.0000)(0.0000)(1.934)(1.975)(2.024)[-.007, 0.408]
25A	0.0263(0.0000)(0.0000)(-.0288)(1.934)(1.975)(1.986)(17.2)	1.1905(0.0000)(0.0337)(0.6271)(1.935)(2.033)[-.302, 0.732]	-0.4445(0.0000)(0.0000)(1.934)(1.975)(2.024)[-.007, 0.408]
26A	0.0263(0.0000)(0.0000)(-.0288)(1.934)(1.975)(1.986)(17.2)	3.9744(0.0000)(0.0351)(0.3287)(1.934)(2.026)[-.279, 0.542]	-0.4445(0.0000)(0.0000)(1.934)(1.975)(2.024)[-.007, 0.408]
27A	0.0263(0.0000)(0.0000)(-.0288)(1.934)(1.975)(1.986)(17.2)	-0.9969(0.0000)(-.2571)(1.711)(1.904)(1.975)[0.859, 0.179]	-0.4445(0.0000)(0.0000)(1.934)(1.975)(2.024)[-.007, 0.408]
28A	0.0263(0.0000)(0.0000)(-.0288)(1.934)(1.975)(1.986)(17.2)	-0.5991(0.0000)(0.0641)(-.4658)(0.5553)(1.413)(1.910)(1.975)	-0.4445(0.0000)(0.0000)(1.934)(1.975)(2.024)[-.007, 0.408]
29A	0.0263(0.0000)(0.0000)(-.0288)(1.934)(1.975)(1.986)(17.2)	-0.2012(0.0000)(0.0394)(-1.144)(1.914)(1.975)[0.696, 1.243]	-0.4445(0.0000)(0.0000)(1.934)(1.975)(2.024)[-.007, 0.408]
30A	0.0263(0.0000)(0.0000)(-.0288)(1.934)(1.975)(1.986)(17.2)	0.1366(0.0000)(0.0298)(1.916)(1.975)(4.083)[0.003, 0.918]	-0.4445(0.0000)(0.0000)(1.934)(1.975)(2.024)[-.007, 0.408]
31A	0.0263(0.0000)(0.0000)(-.0288)(1.934)(1.975)(1.986)(17.2)	0.2366(0.0000)(0.0278)(1.917)(1.975)(3.244)[-.021, 0.810]	-0.4445(0.0000)(0.0000)(1.934)(1.975)(2.024)[-.007, 0.408]
32A	0.0263(0.0000)(0.0000)(-.0288)(1.934)(1.975)(1.986)(17.2)	0.5940(0.0000)(0.0224)(1.918)(1.975)(2.539)[-.038, 0.643]	-0.4445(0.0000)(0.0000)(1.934)(1.975)(2.024)[-.007, 0.408]
33A	0.0263(0.0000)(0.0000)(-.0288)(1.934)(1.975)(1.986)(17.2)	-0.7978(0.0000)(-.0977)(1.936)(2.040)(3.576)[0.195, 0.219]	-0.4445(0.0000)(0.0000)(1.934)(1.975)(2.024)[-.007, 0.408]
34A	0.0263(0.0000)(0.0000)(-.0288)(1.934)(1.975)(1.986)(17.2)	-0.4004(0.0000)(0.1032)(0.2643)(-.3796)(1.938)(2.069)(3.184)	-0.4445(0.0000)(0.0000)(1.934)(1.975)(2.024)[-.007, 0.408]
35A	0.0263(0.0000)(0.0000)(-.0288)(1.934)(1.975)(1.986)(17.2)	-0.2012(0.0000)(0.0490)(0.7274)(-.7430)(1.943)[0.992, 2.261]	-0.4445(0.0000)(0.0000)(1.934)(1.975)(2.024)[-.007, 0.408]
36A	0.0263(0.0000)(0.0000)(-.0288)(1.934)(1.975)(1.986)(17.2)	0.0970(0.0000)(0.0285)(1.926)(1.990)(6.884)[0.034, 0.852]	-0.4445(0.0000)(0.0000)(1.934)(1.975)(2.024)[-.007, 0.408]
37A	0.0263(0.0000)(0.0000)(-.0288)(1.934)(1.975)(1.986)(17.2)	0.1366(0.0000)(0.0270)(1.927)(1.994)(6.038)[0.021, 0.786]	-0.4445(0.0000)(0.0000)(1.934)(1.975)(2.024)[-.007, 0.408]
38A	0.0263(0.0000)(0.0000)(-.0288)(1.934)(1.975)(1.986)(17.2)	0.2366(0.0000)(0.0239)(1.929)(2.001)(5.164)[0.005, 0.686]	-0.4445(0.0000)(0.0000)(1.934)(1.975)(2.024)[-.007, 0.408]
21B	0.0263(0.0000)(0.0000)(-.0903)(1.988)(1.996)(2.046)(17.2)	-1.9908(0.0000)(0.0946)(-.3692)(1.996)(2.204)[-.031, 0.800]	-0.4445(0.0000)(0.0000)(1.988)(1.996)(2.220)[-.123, 0.824]
22B	0.0263(0.0000)(0.0000)(-.0903)(1.988)(1.996)(2.046)(17.2)	-0.5991(0.0000)(0.1156)(-.9032)(1.996)(2.173)[0.104, 0.850]	-0.4445(0.0000)(0.0000)(1.988)(1.996)(2.220)[-.123, 0.824]
23B	0.0263(0.0000)(0.0000)(-.0903)(1.988)(1.996)(2.046)(17.2)	-0.2013(0.0000)(0.1262)(-1.926)(1.998)(2.111)[0.180, 0.974]	-0.4445(0.0000)(0.0000)(1.988)(1.996)(2.220)[-.123, 0.824]
24B	0.0263(0.0000)(0.0000)(-.0903)(1.988)(1.996)(2.046)(17.2)	0.2366(0.0000)(0.1446)(0.8828)(1.995)(2.431)[-.124, 1.156]	-0.4445(0.0000)(0.0000)(1.988)(1.996)(2.220)[-.123, 0.824]
25B	0.0263(0.0000)(0.0000)(-.0903)(1.988)(1.996)(2.046)(17.2)	1.1905(0.0000)(1.996)(2.249)[0.847, 0.206][-.190, 0.928]	-0.4445(0.0000)(0.0000)(1.988)(1.996)(2.220)[-.123, 0.824]
26B	0.0263(0.0000)(0.0000)(-.0903)(1.988)(1.996)(2.046)(17.2)	3.9744(0.0000)(1.996)(2.228)[0.504, 0.123][-.156, 0.853]	-0.4445(0.0000)(0.0000)(1.988)(1.996)(2.220)[-.123, 0.824]
27B	0.0263(0.0000)(0.0000)(-.0903)(1.988)(1.996)(2.046)(17.2)	-0.9969(0.0000)(-.0439)(1.988)[-.128, 0.755][0.998, 1.990]	-0.4445(0.0000)(0.0000)(1.988)(1.996)(2.220)[-.123, 0.824]
28B	0.0263(0.0000)(0.0000)(-.0903)(1.988)(1.996)(2.046)(17.2)	-0.5991(0.0000)(-.0936)(1.988)[-.119, 0.695][0.998, 1.909]	-0.4445(0.0000)(0.0000)(1.988)(1.996)(2.220)[-.123, 0.824]
29B	0.0263(0.0000)(0.0000)(-.0903)(1.988)(1.996)(2.046)(17.2)	-0.2012(0.0000)(-.8276)(0.9638)(1.915)(1.988)[0.515, 0.566]	-0.4445(0.0000)(0.0000)(1.988)(1.996)(2.220)[-.123, 0.824]
30B	0.0263(0.0000)(0.0000)(-.0903)(1.988)(1.996)(2.046)(17.2)	0.1366(0.0000)(0.0847)(1.943)(1.988)(4.091)[-.035, 1.035]	-0.4445(0.0000)(0.0000)(1.988)(1.996)(2.220)[-.123, 0.824]
31B	0.0263(0.0000)(0.0000)(-.0903)(1.988)(1.996)(2.046)(17.2)	0.2366(0.0000)(0.0672)(1.948)(1.988)(3.306)[-.068, 0.981]	-0.4445(0.0000)(0.0000)(1.988)(1.996)(2.220)[-.123, 0.824]
32B	0.0263(0.0000)(0.0000)(-.0903)(1.988)(1.996)(2.046)(17.2)	0.5940(0.0000)(0.0388)(1.959)(1.988)(2.667)[-.101, 0.905]	-0.4445(0.0000)(0.0000)(1.988)(1.996)(2.220)[-.123, 0.824]
33B	0.0263(0.0000)(0.0000)(-.0903)(1.988)(1.996)(2.046)(17.2)	-0.7978(0.0000)(-.0246)(1.996)(2.285)(3.595)[-.138, 0.781]	-0.4445(0.0000)(0.0000)(1.988)(1.996)(2.220)[-.123, 0.824]
34B	0.0263(0.0000)(0.0000)(-.0903)(1.988)(1.996)(2.046)(17.2)	-0.4004(0.0000)(-.0611)(1.995)(2.408)(3.162)[-.151, 0.726]	-0.4445(0.0000)(0.0000)(1.988)(1.996)(2.220)[-.123, 0.824]
35B	0.0263(0.0000)(0.0000)(-.0903)(1.988)(1.996)(2.046)(17.2)	-0.2012(0.0000)(-.2361)(1.995)[-.122, 0.567][0.978, 2.537]	-0.4445(0.0000)(0.0000)(1.988)(1.996)(2.220)[-.123, 0.824]
36B	0.0263(0.0000)(0.0000)(-.0903)(1.988)(1.996)(2.046)(17.2)	0.0970(0.0000)(0.0727)(2.001)(2.051)(6.845)[-.032, 0.995]	-0.4445(0.0000)(0.0000)(1.988)(1.996)(2.220)[-.123, 0.824]
37B	0.0263(0.0000)(0.0000)(-.0903)(1.988)(1.996)(2.046)(17.2)	0.1366(0.0000)(0.0617)(1.999)(2.077)(6.021)[-.051, 0.964]	-0.4445(0.0000)(0.0000)(1.988)(1.996)(2.220)[-.123, 0.824]
38B	0.0263(0.0000)(0.0000)(-.0903)(1.988)(1.996)(2.046)(17.2)	0.2366(0.0000)(0.0447)(1.997)(2.115)(5.169)[-.077, 0.921]	-0.4445(0.0000)(0.0000)(1.988)(1.996)(2.220)[-.123, 0.824]

TABLE B-4. HANDLING QUALITIES PARAMETERS FOR LATERAL-DIRECTIONAL CASES

CASE NO.	$t_{\phi=30°}$ (sec)	ϕ_1/F_{as} (deg in 1 sec/lb)	$\left\|\frac{\phi}{\beta}\right\|_d$	$\measuredangle\left(\frac{\phi}{\beta}\right)_d$ (deg)	$\left\|\frac{\Delta\beta}{\phi_1}\right\|$	$\left\|\frac{\Delta\beta}{\phi_1}\right\| \times \left\|\frac{\phi}{\beta}\right\|_d$	$\frac{\phi_{osc}}{\phi_{av}}$	$\frac{\phi_{osc}}{\phi_1}$	ψ_β (deg)	$\measuredangle\left(\frac{p}{\beta}\right)_d$ (deg)	μ $(\dot{\phi}^{\prime}_{\xi}(3))$	$\frac{N'_{\delta_a}}{L'_{\delta_a}}$	DESCRIPTION
1	1.13	1.23	2.72	56.4	0.092	0.249	0.097	0.176	-87	146	0.86	-0.06	Variations in Dutch Roll Damping and Frequency
2	1.14	1.25	4.34	60.0	0.144	0.625	0.805	0.855	-79	150	-0.28	↓	
3	1.13	1.23	4.22	51.9	0.130	0.549	1.24	0.643	-125	142	2.56	↓	
4	1.14	1.24	1.96	46.9	0.082	0.160	0.087	0.173	-87	137	-0.20	↓	
5	↓	↓	1.99	48.8	0.074	0.148	0.060	0.119	-84	139	0.37	↓	
6	↓	↓	2.07	50.3	0.072	↑	0.022	0.046	-86	140	1.56	↓	
7	↓	↓	↑	43.7	↑	0.149	0	0	-65	134	2.60	↓	
8	↓	1.25	1.29	39.5	0.050	0.064	0.043	0.081	-88	129	0	↓	
9	↓	1.24	1.32	40.9	↑	0.066	0.024	0.046	-87	131	0.69	↓	
10	↓	↑	1.28	43.7	0.049	0.062	0.014	0.015	-89	134	2.10	↓	
11	1.13	1.25	0.66	28.9	0.034	0.023	0.012	0.024	-85	119	0.32	↓	
12	↓	↓	0.73	29.4	0.033	0.024	0.071	0.014	↑	↑	1.28	↓	
13	↓	↓	0.78	29.0	0.031	0.025	0	0	-78	119	3.18	↓	
14	1.18	1.18	4.11	-133	0.131	0.339	1.28	0.64	-299	317	↑	↓	
15	↑	1.19	2.14	-152	0.077	0.163	0	0	-293	298	3.09	↓	
16	1.20	1.17	1.36	9.7	0.061	0.093	0	0	↑	100	3.35	↓	
17	0.93	1.69	4.37	26.6	0.038	0.164	0	0	-68	117	1.33	↓	Variations in Roll Mode Time Constant
18	0.96	1.60	4.09	33.6	0.032	0.212	0.028	0.057	-78	124	1.39	↓	
19	1.04	1.40	3.34	46.9	0.072	0.239	0.061	0.117	-87	137	1.08	↓	
20	1.41	0.98	1.92	66.9	0.129	0.247	0.138	0.235	-87	160	0.60	↓	
21	3.83	1.12	2.71	56.4	1.43	3.88	2.95	2.94	-7.0	146	-1.0	-1.0	Variations in Turn Coordination Characteristics — Nominal $\|\phi/\beta\|_d$
22	1.24	1.18	2.71	36.4	0.466	1.26	0.373	0.871	↓	↓	↓	-0.30	
23	1.17	1.20	2.70	56.5	0.074	0.200	0	0	↓	↓	↓	-0.10	
24	1.13	1.23	2.70	56.4	0.120	0.323	0.128	0.240	-187	↓	↓	0.12	
25	1.07	1.28	2.71	↓	0.324	0.879	0.372	0.656	↓	↓	↓	0.60	
26	1.01	1.43	2.71	↓	0.489	1.32	1.78	0.993	↓	↓	↓	2.00	
27	—	1.31	2.70	↓	0.984	2.66	-1.60	3.34	-74	↓	0	-0.50	
28	1.20	1.27	2.70	↓	0.613	1.66	-9.86	2.03	-74	↓	↓	-0.30	
29	1.16	1.23	2.73	↓	0.184	0.503	0.340	0.587	-80	↓	↓	-0.10	
30	1.14	1.21	2.71	↓	0.078	0.212	0.087	0.168	-254	↓	↓	0.07	
31	1.13	1.20	2.70	↓	0.107	0.289	0.126	0.227	↓	↓	↓	0.12	
32	1.12	1.17	2.71	↓	0.139	0.431	0.219	0.341	↓	↓	↓	0.30	
33	1.16	1.39	2.71	↓	1.07	2.88	-1.09	4.61	-87	↓	1.0	-0.40	
34	1.16	1.29	2.71	↓	0.368	1.54	-2.69	2.37	-87	↓	↓	-0.20	
35	1.13	1.23	2.74	↓	0.296	0.810	1.37	1.17	-94	↓	↓	-0.10	
36	1.14	1.20	2.71	↓	0.072	0.196	0.098	0.183	-267	↓	↓	0.03	
37	1.14	1.19	2.70	↓	0.087	0.233	0.122	0.220	↓	↓	↓	-0.07	
38	1.15	1.16	2.70	↓	0.111	0.300	0.171	0.284	↓	↓	↓	0.12	
39	1.13	1.23	0.921	56.2	0.113	0.104	0	0	0	↓	(0.18)	-0.003	$\dot{\phi}^{\prime}_{\xi}(3)$ Variations — Low $\|\phi/\beta\|_d$
40	1.21	1.15	↓	↓	0.373	0.346	0	0	0	↓	(0.80)	↓	
41	1.07	1.35	↓	↓	0.236	0.236	0.078	0.128	-174	↓	(-0.39)	↓	
42	1.01	1.48	↓	↓	0.663	0.611	0.373	0.363	-174	↓	(-1.13)	↓	
21A	1.47	1.00	↓	↓	1.88	1.73	0.43	1.07	-10	↓	-0.99	-0.95	Turn Coordination Variations — Low $\|\phi/\beta\|_d$
22A	1.17	1.20	↓	↓	0.253	0.233	0.033	0.105	↓	↓	-0.99	-0.30	
23A	1.11	1.28	↓	↓	0.083	0.076	0	0	↓	↓	-0.97	-0.10	
24A	1.07	1.34	↓	↓	0.124	0.114	0	0	-188	↓	-1.0	0.12	
25A	1.02	1.46	↓	↓	0.463	0.427	0.191	0.310	↓	↓	↓	0.62	
26A	0.91	1.81	↓	↓	0.951	0.877	0.613	0.644	↓	↓	↓	2.23	
27A	1.38	1.07	↓	↓	1.13	1.04	1.61	1.20	-78	↓	0	-0.49	
28A	1.22	1.17	↓	↓	0.390	0.344	0.377	0.390	↓	↓	0	-0.30	
29A	1.13	1.23	↓	↓	0.156	0.144	0.070	0.145	↓	↓	0.01	-0.10	
30A	1.08	1.33	↓	↓	0.083	0.078	0	0	-256	↓	0.01	0.07	
31A	1.07	1.35	↓	↓	0.129	0.119	0.049	0.096	↓	↓	-0.01	0.12	
32A	1.03	1.43	↓	↓	0.239	0.220	0.094	0.170	↓	↓	0	0.30	
33A	1.37	1.06	↓	↓	1.44	1.32	-3.29	1.94	-92	↓	0.95	-0.39	
34A	1.22	1.16	↓	↓	0.629	0.380	0.646	0.770	↓	↓	0.92	-0.20	
35A	1.15	1.22	↓	↓	0.272	0.250	0.170	0.311	↓	↓	0.86	-0.10	
36A	1.08	1.33	↓	↓	0.082	0.073	0	0	-270	↓	-0.13	0.05	
37A	1.06	1.36	↓	↓	0.105	0.097	0.048	0.094	↓	↓	0.04	0.07	
38A	1.06	1.37	↓	↓	0.153	0.141	0.070	0.132	↓	↓	1.24	0.12	
21B	4.58	0.03	4.07	53.4	4.34	17.7	62.0	11.7	-5	143	-0.98	-0.93	Turn Coordination Variations — High $\|\phi/\beta\|_d$
22B	1.48	1.09	↓	↓	0.564	2.28	0.635	1.61	↓	↓	-0.94	-0.30	
23B	1.27	1.04	↓	↓	0.064	0.260	0.073	0.143	↓	↓	-0.82	-0.10	
24B	1.09	1.28	↓	↓	0.113	0.439	0.194	0.331	-188	↓	-1.12	0.12	
25B	0.79	2.31	↓	↓	0.267	1.09	0.948	0.822	-182	↓	-1.02	0.62	
26B	0.63	3.97	↓	↓	0.363	1.48	3.36	1.13	-182	↓	-1.01	2.23	
27B	—	0.42	↓	↓	2.11	8.6	-1.03	11.1	-71	↓	0.03	-0.49	
28B	18.9	0.74	↓	↓	1.06	4.3	-1.49	5.60	-71	↓	0.03	-0.30	
29B	1.23	1.18	↓	↓	0.233	0.948	0.912	1.17	-77	↓	0.13	-0.10	
30B	0.85	1.87	↓	↓	0.070	0.286	0.121	0.210	-247	↓	-0.21	0.07	
31B	1.04	1.38	↓	↓	0.091	0.372	0.173	0.278	↓	↓	-0.12	-0.12	
32B	0.87	1.96	↓	↓	0.117	0.476	0.284	0.383	↓	↓	-0.03	0.30	
33B	--	0.26	↓	↓	2.74	11.2	-0.878	18.3	-90	↓	0.99	-0.39	
34B	27.0	0.99	↓	↓	0.888	3.62	-1.20	3.93	↓	↓	0.98	-0.20	
35B	10.0	0.94	↓	↓	0.421	1.71	-4.47	2.72	↓	↓	0.98	-0.10	
36B	0.97	1.57	↓	↓	0.061	0.231	0.135	0.227	99	↓	-0.25	0.03	
37B	1.18	1.02	↓	↓	0.072	0.293	0.168	0.267	-266	↓	-0.03	0.07	
38B	0.77	2.16	↓	↓	0.084	0.341	0.227	0.329	99	↓	1.11	0.12	
43	0.96	1.60	4.08	33.6	0.052	0.211	0.028	0.037	-79	146	1.39	-0.06	L_{δ_a} Variations
44	1.91	0.63	↓	↓	0.162	0.659	0.421	0.393	↓	↓	0.53	↓	
45	3.00	0.52	↓	↓	0.204	0.830	0.818	0.846	↓	↓	0.44	↓	
46	3.80	0.52	↓	↓	0.207	0.847	0.873	0.871	↓	↓	0.44	↓	
47	5.0	0.49	↓	↓	0.221	0.900	1.09	0.931	↓	↓	0.41	↓	
48	1.00	1.50	1.92	66.9	0.083	0.164	0.069	0.127	-94	↓	0.93	↓	
49	2.01	0.71	↓	↓	0.180	0.345	0.242	0.370	-87	↓	0.43	↓	
50	3.02	0.56	↓	↓	0.226	0.434	0.362	0.493	-80	↓	0.34	↓	
51	4.0	0.50	↓	↓	0.238	0.493	0.465	0.583	↓	↓	0.30	↓	
52	5.0	0.44	↓	↓	0.293	0.561	0.603	0.679	↓	↓	0.27	↓	

☆U.S.Government Printing Office: 1986 — 748-061/60573